AN INVESTIGATION INTO THE SCIENCE
OF BI-COMPONENT BLENDING
USING FIBERS WITH WIDELY DIVERGENT PROPERTIES

A THESIS

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Approved:

Chairman

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DEDICATED

to

W L H

And gladly wolde he lerne, and gladly teche.

...Chaucer

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TABLE OF CONTENTS

(Continued)

TABLE OF CONTENTS (Concluded)

LIST OF TABLES

(Continued)

LIST OF TABLES (Continued)

(Continued)

LIST OF TABLES (Concluded)

LIST OF ILLUSTRATIONS

SUMMARY

This program has been designed as exploratory research to attack some of the questions surrounding the science of fiber blending. Detailed investigations have been concerned with the concepts of matching either break elongations or shape of the stress-strain curves for blend members in a bi-component blend.

Continuous filament yarns were employed to produce untwisted, "composite" blends in 3000 denier model yarns. Investigations were made of all bi-component combinations of nylon, Dacron, acetate and viscose, and at the 25, 50 and 75 percentage levels.

Numerous individual ends of continuous filament yarns were aggregated to produce the model yarn structure. With no twist inserted, all ends, when loaded, were lying side by side and acting in parallel.

Blend efficiency was defined as a percent utilization of maximum strength potential. It was found that, for a composite blend imposed of blend members with dissimilar rupture elongations, an increase in the percentage content of the stronger fiber will increase blend efficiency. However, for composite blends with similar or matched rupture elongations, the percentage content of either fiber will have no effect on blend efficiency, which will be maximized and approaching 100 percent for this case.

The discussions on the strength of a composite yarn have been extended to explain why, in "intimate", staple blends, the addition in low percentages of certain strong, high elongation fibers, to weaker,

low elongation fibers, may actually cause a blend strength loss when compared with 100 percent of the latter.

Statistical methods employing analysis of variance revealed that viscose or nylon, when in combination with over 50 percent Dacron, was significantly stronger than the similar fiber when not in combination. However, the addition of Dacron or viscose to acetate and viscose to nylon revealed no significant strength differences when compared to similar fibers when not in combination.

The author believes, that on the question of the strength compatability of two blend members, the shape of the stress-strain curves of the components should be matched, but only up to the strain level that would be the expected maximum to be reached by the fibers during serviceability. It should be immaterial to concern onesself with the shape of the stress-strain curve above this level.

The author further believes that the strength testing of blends at strain levels below rupture warrants serious further consideration.

CHAPTER I

INTRODUCTION

Blending

The idea of blending or mixing dissimilar materials for mutual benefit or improved total performance is one of the mainstays in the construction of our universe. Plant life and living matter are a composite of different materials uniquely molded and blended in exacting proportions. Each component plays a vital role, and totality is lost without every constituent doing its part.

Modern scientific techniques have paralled nature somewhat in the aspects of blending. Metallic alloys, color mixing and fuel mixing are examples, to name but a few. The textile industry, in keeping abreast of modern scientific development, is making widespread use of the concepts of fiber blending.

No one fiber is of such a nature that its properties are universal for all end use requirements. Each fiber has both desirable and less desirable features. While its desirable points may serve it well under certain applications, it may react less favorably under other conditions.

Therefore one approach to this problem has been to combine the more favorable properties of two or more fibers together into a blended aggregate containing a measure of the properties of its constituent members. The result is a structure with known performance characteristics designed to fit certain particular end use requirements.

Whytlaw (1) describes the complex objectives of blending as a search for:

> (a) a combination of fibers having adequate processing properties for the spinner;
> (b) a combination which can be manufactured into a fabric at a price accessible to important segments of the trade;
> (c) one capable of meeting certain fabric performance requirements; and
> (d) one versatile enough to respond to the repeated changes of the textile industry, yet assuring a fair margin of profit.

These objectives have been the major drives behind the phenomenal increase in the appearance and consumption of blends in textiles in recent years.

The blends available today, which are yet but a foretaste of what the future holds in store, have already proven to outperform the once unassailable "old standby" fabrics. However, this situation regarding the blends is compounded and complicated by its very nature---that we have a "blend" or mixture of differing members.

There are, today, literally hundreds of natural and man-made fibers, each with its own intrinsic properties. They offer an enormous storehouse from which to choose the constituent blend members. Add to this the many varying types and forms in which each fiber may be obtained, and the varying methods with which fibers in general may be blended; and the result is an infinite variety of combinations or blend possibilities, so large that it staggers the imagination.

Purpose for the Research

It is for the reason just mentioned that our research program materialized.

It has been difficult for technical information to keep pace with mushrooming new developments in the field of blends. Martindale (2) and Nuding (3) have commented on this wide gap between knowledge and development. Backer (4) and Hoffman (5) have recently expressed the belief that certain phases of the science of blending warrant further study.

This author has found a paucity of scientific knowledge in certain areas pertaining to blends, and conflicting opinions in other areas.

To obtain answers to some of the questions underlying the basic physical tenets and principles of blending textile fibers has been the effort of our research program. Application of the results obtained from continuous filament investigations may be extended to apply to staple fiber blends.

It is hoped that this investigation, acting in a capacity of exploratory research, may uncover areas of interest in addition to our presently designed program, so that much needed research work into the science of fiber blending can be continued.

Statement of the Problem

The main problems considered in this study are the following:

Does matching break elongations of blend members produce maximum strength efficiency in the resultant blend?

What effect does the initial or Young's modulus of the blend members have upon resultant blend strength?

Why does the addition of up to 40 percent of certain stronger fibers to weaker ones actually cause a loss in strength?

Will Peirce's "weak-link" theory cause an expected strength loss in a composite of multiple ends of continuous filament yarn when compared with single ends of continuous filament yarn?

Can latent strength increases arising from lateral or transverse frictional forces at strains above the rupture elongation of the lower member be corroborated for our blend combinations?

Does the fabric situation materially increase lateral or transverse frictional forces above those levels found in twisted yarn structures?

The ensuing discussion is directed to finding solutions to some of the above questions. This particular research program will deal in detail with the nature of the first four questions.

The remaining questions will be dealt with in CHAPTER VI, RECOMMENDATIONS. Some basic investigations into these areas have been done by the author within the range of exploratory research, although insufficient data was collected to make any committal conclusions.

Additional recommendations, uncovered during the investigations and deemed worthy of warranting further study, are also presented.

Survey of the Literature

> ...fibers, each not more than two or three cubits in length, so tightly bound together in the case of a rope one hundred cubits long (would require a great force to break them). Can you not hold a hempen fiber so tightly between your fingers that I, pulling on the other end, would break it before drawing it away from you? Certainly you can. And now when the fibers of hemp are held not only at their ends, but are grasped by the surrounding medium throughout their entire length is it not manifestly more difficult to tear them loose from what holds them than to break them? But in the case of the rope the very act of twisting causes the threads to bind one another in such a way that when the rope is stretched with a great force the fibers break rather than separate from one another. At the point where a rope parts the fibers are, as everyone knows, very short, nothing like a cubit long, as they would be if the parting of the rope occurred, not by the breaking of the filament, but by their slipping over one another.

Thus spoke the brilliantly enlightened Galileo (6) in 1638, as quoted by Backer (7).

It was not until 1907, almost 300 years later, that Gegauff (8) published his paper on the strength and elasticity of twisted cotton yarns. This work by Gegauff was destined to lie dormant until its rediscovery by Hearle (9) in 1958.

In 1950, Platt (10) published the initial investigation into the field of the mechanics of yarn structures. Platt's investigations were with twisted continuous filament yarns, but his conclusions were extended to also apply to tightly twisted spun yarns where fiber slippage is negligible.

The initial assumptions assumed by Platt (11), and similar to those assumed by Gegauff, are outlined by Backer (12) as follows:

> ...a series of fibers infinitely long, uniform in cross section, and uniform in mechanical properties. The fibers are twisted together so as to form a series of uniform helices, with each fiber lying on a helix of fixed radius (and staying at that radius). Each fiber has properties constant along its length; each fiber is similar to its neighbor in geometry and in mechanical properties. We assume that there is no interaction between the fibers and we consider each fiber element to be so slender that it can withstand only tensile forces along its axis.

Platt's initial investigation discussed fiber strain as a function of yarn extension and helix angle. The fiber stress-strain properties determine tensile forces which are integrated across the yarn to yield a measure of the load on the yarn at a particular strain.

There have been, however, modifications to this initial approach by Platt that came about as a result of the realization of certain effects not initially included.

Platt, Klein and Hamburger (13) extended this initial work of

Platt to include the variability of the stress-strain properties of fibers. This set aside Platt's original assumption of uniformity in fiber actions.

Another assumption made by Platt of the uniformity in fiber position in a twisted yarn helix led to investigations disproving this case with the discovery of "filament migration", i.e., the varying of the radial position of any one fiber along the length of the yarn.

Treloar (14) investigated the geometry of multi-ply, continuous filament yarns and expressed twist retraction and filament helix angle as functions of twist.

To corroborate these expressions of Treloar, Tattersall (15) designed a laboratory machine with which he twisted his experimental yarns and cords. A comparison with commercially twisted yarns was made. Tattersall's laboratory twisting machine was composed of a twisting head geared to a revolution counter. Between this twisting head and a movable trolley 50 inches away was inserted the twist.

Tattersall's results showed quite good agreement between Treloar's theory and data obtained from commercially twisted yarn. However, very poor agreement was found using data obtained from the laboratory machine twisted yarns. Tattersall concluded that the commercially twisted yarns and those yarns twisted on the laboratory machine did not have the same physical properties.

Further light on this problem was shed by Riding (16). He concluded that it was reasonable to suppose that in continuous filament yarns the path of each filament is not a perfect cylindrical helix but one whose radius varies along the length of the yarn.

Previous investigations by Morton and Yen (17), and later Morton alone (18), had observed "filament migration" in staple yarns. Their technique was to use a small portion of colored "tracer" fibers incorporated into the yarn early in its manufacture. The finished yarn, when immersed in a liquid of equivalent refractive index, clearly yielded the path of the tracer filaments.

Riding (19) used this tracer technique with continuous filament yarns by incorporating one colored yarn into a high denier, model yarn. He was thus able to substantiate filament migration in twisted, continuous filament yarns.

The results of these investigations by Riding (20) showed that the two basic assumptions of Treloar's theory, i.e., "...each filament in the yarn has the form of a simple helix whose axis coincides with the yarn axis" and "...the filaments do not change their length on twisting" are incompatible.

Riding (21) discussed the differences found by Tattersall between twisting on a laboratory machine and commercial twisting "...as an essential difference between 'continuous twisting' processes, and the twisting of a fixed length or 'static twisting', arising from the greater ease of filament migration in continuous twisting." Tattersall's (22) observation of the ease of formation of kinks in statically twisted yarn provided further evidence.

Riding (23), therefore, designed a laboratory twisting machine which he showed could produce "continuously" twisted yarn. This was accomplished by control of the length of the twisting zone, and use of an improved yarn tension and control system.

It is worth noting that Stansfield (24), in his investigations of the geometry of multi-filament structures, although using a form of "static twisting", claims good agreement with Treloar's theory.

There are many unanswered questions concerning the exact nature of the insertion of twist, but Riding (25) suggests "...that the occurrence of migration is connected with the conditions existing in the region where the twist is being inserted into the yarn. This precise region is yet to be well defined".

The presence of filament migration should help to reduce the formation of kinks and buckling due to strained outer filaments, as discussed by Tattersall (26), Riding (27), Hearle, El-Behery and Thakur (28), Hearle and Thakar (29), and Zurek (30).

A more recent work by Riding (31) has investigated certain migration parameters including period and frequency of migration.

However, Kilby (32) further discusses migration theory as compounded by his compression theory. Kilby recognizes the experimental evidence favoring filament migration in commercially twisted yarns. Yet in the twisting of short lengths of yarn by the static method, migration may be partially or wholly inhibited. If this is the case, Kilby suggests that the lateral pressure and constraints caused by the transverse components of the tensions in the outer filaments will compress the inner filaments as in axial compression. It may result that these inner filaments can no longer follow helical paths, so that kinking and buckling will arise to make more complex the treatment of this problem.

In addition to a neglect of filament migration, Platt and Gegauff, in their discussions, also neglected the transverse or lateral frictional forces developed in twisted yarn structures.

Hearle, El-Behery and Thakur (33) state that Hearle (34) had earlier shown "... that transverse stresses, which are taken to be the same in all directions perpendicular to a fibre axis, may be as large as one-third of the tensile stresses in the fibre at the center of a highly twisted yarn. These transverse forces will influence the fibre deformations, and will contribute an appreciable component to the yarn tension."

Zurek (35) states that within the body of the yarn, the frictional forces resulting from pressures are two to three times those found at the exterior of the yarn.

The effects of these lateral frictional forces, and an estimation of their magnitude, have been pictorially presented as photographs of cross-sectional deformations in twisted yarns, and yarn and fabric in tension, by Hearle and Thakur (36) and Backer (37). Backer notes that surprisingly, maximum fiber packing density has not been found at the center of the yarn, but rather three-fifths of the way out.

Kemp and Owen (38) concerned themselves with the effects these lateral frictional forces might have on yarn strength. In their investigations using nylon/cotton blends, the strength of the yarn showed no material strength losses at strains above the break elongation of the cotton component. The cotton was actually continuing to break, and thus added a latent increase in strength to the yarn above its break elongation. It was concluded that portions of the cotton fiber were still locked into the twisted yarn structure at points where it had not previously broken. Therefore, with increasing strain, the cotton was able to break again and again, and continuing to add a component of strength to the yarn.

Kemp and Owen, working with a 60/40 nylon/cotton blend, measured the number of fiber breaks and mean fiber length of the cotton component at various strain levels. While a few fibers were shown to break at 5 percent extension, there were 50 breaks at 8 percent extension, 100 breaks at 10 percent extension, and over 200 breaks at 15 percent extension. The mean fiber length has reduced from 2.5 cm. to 1.5 cm. at 10 percent extension, and to under 1.0 cm. at 15 percent extension.

Koritskii (39) experienced similar results when he also worked with nylon and cotton, and states "...that the cotton fibers contribute to load carrying capacity under tension at extensions exceeding their extension at rupture".

Backer (40), with K. Machida (41), discussed their program extending the work initiated by Kemp and Owen. A 4000 denier model yarn was composed of 70/34 nylon yarns and 100's cotton yarns, twisted to a twist multiple of 3.0. Curves are presented to quantitatively show the increased strength effect which the cotton component offered at strains above its break elongation.

Machida was able to determine the lateral pressure developed within this model yarn structure when subjected to axial tension. The pressure at the center of the yarn was shown to vary as the first power of the tensile load on the yarn and as the square of the twist in the yarn.

Backer (42) further discusses that "...instead of measuring the lateral pressures within the structure of a blended yarn, one can measure the average lengths of the broken segments of the low elongation fiber component and back calculate what the pressures are." The ability for these low elongation fibers to continue to rupture are discussed as a function of their "critical length", i.e., whether the fibers are of adequate size for sufficient tension to build up and rupture the fiber. This "critical fiber length" is dependent upon the product of the local pressure and the coefficient of friction, and is presented in a graphical solution employing a trapezoid composed of the applicable parameters.

Backer (43) and Hoffman (44), in discussing the important and significant strength contribution of a low elongation fiber as it continues to break at strains above its break elongation, express belief that a woven fabric structure would materially increase this strength contribution above the levels found in a twisted yarn structure. This is due to the compressive nature of the forces found at the weave interlacings of the two yarn systems in the fabric.

Backer (45) discusses stress-transfer and rupture propagation in a blend following initial fiber breakdown. His conclusions are:

> ...if a low elongation and a high elongation fiber are blended together, the high elongation component should also have higher strength if its full elongation and strain evergy capacity is to be used effectively. And further we state that clumping or grouping together of similar fibers should be avoided in blended structures and maximum effort should be undertaken to get a homogeneous blend distribution.

Backer (46) goes on to suggest that from a standpoint of rupture propagation, blend members of similar stress-strain properties would be undesirable partners.

Hearle and Thakur (47) have shown similar interest in rupture propagation and the modes of breakage in twisted continuous filament yarns.

Returning to the relationships between fiber properties and blended yarn properties, Noshi, Ishida and Shimada (48) state that "the simultaneous breakage of two different filaments is the best condition for their blending".

Sattler (49) concurs; "Blending components should have approximately the same elongation at break. In an ideal case, the stress-strain curves would be geometrically similar".

Coplan (50) too, agrees that "If the stronger of the fiber types in a blend has a markedly different extensibility from the weaker, the two types do not add the full components of their respective strengths at a time when the less extensible one fails. The blend yarn will be weakened thereby".

Nuding (51) states that "the load-extension characteristics should be similar since, in spite of a higher breaking load in the single components, the mixed yarn might be weaker. In loading the yarn, the fibers with the lower extensibility would take the whole load before the more extensible ones came under strain and a premature break would ensue".

Whytlaw (52) expressed thoughts similar to Nuding. The statement by Nuding is believed to be the reason that the addition of low percentages of from 25 to 40 percent of certain stronger fibers to weaker ones may actually cause a strength loss in the resultant blend. This observation has been recorded by Nuding (53) and Sayre (54) in addition to many others. Nuding's work was with the addition of cotton to viscose rayon, while Sayre's experiences were with the addition of nylon, orlon and Dacron to viscose rayon.

Hamburger (55) states "...that in order to produce a composite yarn the tenacity of which, for all blend percentages, exceeds that of a yarn composed solely of the weaker component, the stress-strain curves of the two materials must be so related that at the ultimate elongation of the weaker component, the load supported by the stronger component must exceed the tenacity of the weaker component".

Koritskii (56) experienced blend strength losses with the addition of up to 40 percent Kapron (nylon) to cotton. Koritskii relates this effect to the properties of the fibers by his equation for the strength of a "composite" yarn as a function of the strength of a given count of the yarn of lower breaking elongation, the percentages of the two components, the modulus of the yarn of higher elongation and the elongation at rupture of the composite yarn.

In two distinct investigations by Koritskii (57,58) concerning the estimation or predetermination of the strength and extension of blended yarns either as intimate or plied yarn blends, theoretical values calculated from his theory yielded close agreement with actual values obtained from the yarns tested.

Owen (59) has recently investigated the prediction of the strength and shape of the stress-strain curve of a blended yarn as determined from the stress-strain curves of the individual components. Owen (60), discussing stress-contribution curves obtained from various blend combinations, believes "...that the two constituents of a blend behave independently at all strains". Stress-contribution curves therefore appear independent of the types of fiber blended or the blend percentages. Thus with the separate stress-strain curves of the two blend components, and the stress-contribution curve of the component of lower elongation, a stress-strain curve for any proportional blend of the two should be possible to predict.

Concerning the prediction of blend strength, Owen (61) states, "If at the breaking strain of the components of lower breaking strain, the stress in the other component is approaching breaking stress, then the variation of strength with blend proportion will be nearly linear".

Noshi, Ishida and Shimada (62), in their theoretical and actual investigations, conclude that "the best condition for blending where tensile rupture is the aim is that the content of the filament of smaller breaking elongation be comparatively small and that the yarn be twisted over half the maximum number of twists".

Louis, Fiori and Sands (63,64), blending cottons differing in break elongation, have stated "...that there is no apparent advantage, from the standpoint of textile quality, in blending low and high elongation fibers---whether in blends of natural-natural or natural-synthetic fibers". Superior properties were obtained using the high elongation fibers.

Dennison and Leach (65) commented on the relation between blend strength and the stress-strain properties of the individual members. However, the loss in strength sometimes accompanying the addition of high tenacity, high elongation fibers to other weaker ones has been discussed by Dennison and Leach as it pertains, not only to break elongations, but also to relative Young's moduli.

Viscose rayon and cotton are each shown to have a relatively high Young's modulus. The fiber with the higher modulus carries a disproportionate share of the load, and may take up most of the stresses arising from the initial strain. Since the other fiber, which may be stronger, is not carrying its proportionate share of the load, the blended yarn strength may be less than that of either of the blend components viewed singly.

Dennison and Leach go on to show that the addition of from 25 to 50 percent of low modulus Dacron, nylon or cotton to viscose rayon, with a higher modulus, causes the latter to carry more of its share of the load, and thus break at a lower total load than would have resulted if all cotton or viscose rayon had been used.

Wool or cellulose acetate, however, were shown to have rather low moduli, and therefore, when blended with another fiber of greater modulus, almost proportionate strength increases occur.

Dennison (66) has recently expressed the feeling "...that both modulus and break elongation should be as closely matched as possible for the blend components in order to realize maximum blend strength".

The use of continuous filament yarns as blend members, which is the design of this research program, has proven successful in the past, as recorded in the literature by Machida, working with Backer, Noshi et al., and Matukonis (67).

Matukonis, working with Kapron (nylon), viscose and acetate, investigated, both theoretically and actually, the redistribution of load in two components, acting in parallel under constant stress, and as a function of time.

Design of the Research Program

The research program comprising this thesis will use continuous filament yarns to remove any effects due to fiber slippage as is often the case with staple fiber yarns.

In an attempt to resolve some of the questions concerning the matching of break elongations and fiber modulus in blends, a comparison will be made of significant differences among blend strengths of combinations of nylon, Dacron, acetate and viscose. Significance due to differing percentage levels in the blend will also be investigated.

The use of both single end and multiple end continuous filament yarn structures offer a comparison with Peirce's (68) "weak-link" theory, in which a specimen can be no stronger than its weakest link. This was a reversal of many earlier beliefs, of which Galileo (69) was one.

CHAPTER II

MATERIALS AND INSTRUMENTATION

Fibrous Materials

The following fibrous materials, in continuous filament yarn form, were used in this experimental program:

1. The polyester yarn was DuPont Dacron Type 52, 220 denier, 50 filaments, no twist. It had a tenacity of 8.5 grams per denier, and an elongation of 12.5 percent.

2. The polyamide yarn was DuPont nylon, Type 680, 200 denier, 34 filaments, 0.75 turns of Z twist. It had a tenacity of 5.9 grams per denier, and an elongation of 29.0 percent.

3. The viscose rayon yarn was Celanese viscose, 150 denier, 60 filaments, 3 turns of S twist. It had a tenacity of 2.2 grams per denier, and an elongation of 19.0 percent.

4. The cellulose acetate yarn was Celanese acetate, 150 denier, 40 filaments, 2 turns of Z twist. It had a tenacity of 1.2 grams per denier, and an elongation of 28.0 percent.

Processing Equipment

The following equipment was employed in processing the materials for this program:

1. Whitin Model B Novelty Twister with Model C Novelty Yarn Attachment.

2. Saxl Precision Tension Meter.

3. Foster Winder, Model 75D.

4. Laboratory Twisting Machine, consisting basically of an Alfred Suter Twist Tester, with certain modifications and additions. These include the use of additional equipment, such as a hand warping creel, yarn guides, a porcelain eyeboard, Will chemical laboratory stand, and a double disc compensator yarn tension apparatus.

Testing Equipment

The following testing equipment was employed in this program:

1. Microscope illuminator, Spencer Lens Co., Model 370.

2. AO Spencer stereo microscope.

3. Russian toolmaker's microscope.

4. Instron Electronic Tensile Tester, Model TT-C.

5. Burrough's Algebraic Computer, Model B-220. Concurrent with the use of the computer was the use of an IBM Keypunch, Model 026, and an IBM Printer, Model 407.

CHAPTER III

EXPERIMENTAL PROCEDURE

Sample Preparation

The particular fibers used were chosen for their widespread market accepatance both in their own right and as blend members. The properties of the fibers, particularly break elongation, were specifically chosen to vary the strain break from 12 to 19 to 29 percent.

The yarns were received from the manufacturers as described in CHAPTER III, MATERIALS AND INSTRUMENTATION, "Fibrous Materials". All yarn was stored in the dark when not in use to prevent any light degradation to the yarn.

As an alternative to removing the "producer's twist" in the yarns, it was assumed that this small value of twist would be insignificant in subsequent measurements. Riding (70), Taylor et al. (71), and Treloar and Riding (72) have commented that the presence of this small degree of twist is advantageous to the handling of the yarn, and this author has found that case to be true. However, in measurements of yarn retraction, Tattersall (73) had decided to remove this manufacturer's twist during his investigations.

Viscose was the only fiber received with S twist, as opposed to Z twist in the nylon and acetate, and no twist in the Dacron. It had been originally planned in this investigation to do experimentation using the laboratory twisting machine as found in CHAPTER VI, RECOMMENDATIONS, "Twisting on a Laboratory Machine". To remedy what was thought might be possible ramifications due to differences in twist directions, it was decided to retwist the viscose. By inserting 5 turns of Z twist, the S twist would be removed and 2 turns of Z twist would be inserted. All twisting was done on a Whitin Model B Novelty Twister. Operational data for the twister may be found in Table 12.

The twisting tension, designed to be as low as possible, was measured with a Saxl Precision Tension Meter. The tension between the nip of the feed roll and the traveler was negligible. However, the tension between the nip of the feed roll and the supply package on the creel ranged between 30 and 50 grams, and thus at times achieved a maximum twisting tension on the viscose of 0.33 grams per denier.

This high twisting tension was a result of the setup of the supply package in the creel. The Whitin Novelty Twister is a ring downtwister. The yarn supply is fed to the twisting zone from an overhead yarn creel. The conical shaped producer's supply package was used directly in the yarn creel. Even with a buildup of the diameter of the support pegs in the creel, the yarn supply package did not rotate and feed yarn as smoothly as would have been desired, and thus the excessive twisting tension.

It is believed that as a result of this tension, the retwisted viscose exhibited a change in break elongation from 18 percent before twistint to 12 percent after twisting. Hearle, El-Behery and Thakur (74) also experienced this permanent deformation due to twisting tension, and discuss the effect as a function of the elastic behavior of the particular material being twisted. Backer and Hearle *et al*. (75) further discuss these effects of twisting tension causing permanent deformation to reduce breaking extension as in acetate. However, for a material with good elastic recovery, such as nylon, upon removal of the tension, center filaments may buckle, causing migration and a more even distribution of stresses and fiber extensions. This often leads to an increase in yarn breaking extension.

To continue with the program as executed, all yarn samples throughout the program were used in continuous filament form. The use of continuous filament was to remove any effects of inter-fiber slippage as might be found in staple fiber yarns.

The first phase of this research program consisted of preparing and testing blended yarns composed of two ends of continuous filament. One end of each blend member was used, and samples were prepared using all possible bi-component combinations of the nylon, Dacron, acetate and viscose. These yarns were prepared as "composite" blends, i.e., lying side by side and acting in parallel with no twist inserted. Table 13 gives the exact percentages and denier of the prepared samples. In the actual testing of these samples, the two ends were led directly off of their respective producer's packages and to the jaws of the Instron tester where they were tested.

The second phase of this research program, as the previsous, prepared "composite" blends as opposed to "intimate" blends which would be coherently twisted structures. Again, all ends were assumed to be lying side by side, and acting in parallel, with no twist inserted. However, in this case, a multiple number of ends of continuous filament yarn were aggregated to compose a model yarn structure.

Model yarns composed of approximately 3000 denier were prepared and tested. The nylon, Dacron, acetate and viscose were blended as bi-components at the 25, 50 and 75 percentage levels. Samples of 100 percent of each of the fibers were used as standards for comparison. Table 14 gives the exact percentages and denier of all the model yarn samples prepared.

To achieve particular blend levels, it was necessary to divide the approximate 3000 total denier into respective deniers for each component. Then, a suitable number of ends were aggregated to supply the required denier. This necessitated the breaking down of producer's packages, on which the yarn was received, to smaller paper tubes, so that multiple ends of each individual fiber could be blended. These smaller packages were produced on a Foster winder. Due to the elastic properties of the fibers being processed, and particularly nylon, it was advantageous to produce the paper tube packages with a minimum of winding tension. If this were not done, it was often difficult and at times impossible to remove the package from the winding spool without damaging the package wind, since the grip of the paper tube on the spool was so tight. The tension adjustment on the Foster Winder was accordingly set in its minimum position. Any change in twist due to the over-end winding off the producer's package was assumed to be insignificant.

When a number of ends were aggregated to produce the multiple end, 3000 denier model yarn, the supply packages for these ends were supported in a hand warping creel. The creel was positioned at an angle of approximately 30 degrees from the horizontal, which aided in diminishing any slough-off of the yarn from the paper tube packages upon unwinding. Also the slight inclination of the creel prevented any supply packages from riding in a horizontal plane and thus falling off their support pegs in the creel.

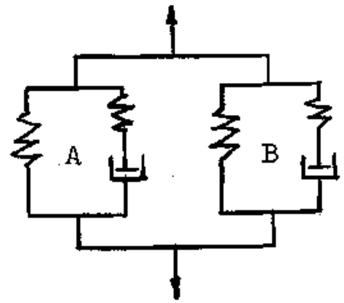
The multiple ends were aggregated from their positions in the creel and fed through two yarn guides supported on weighted down Will chemical laboratory stands. The yarn guides were used to reposition the model yarn structure to such a position that it could be easily hand fed to the Instron Tester jaws for testing.

The different blend and percentage samples were aggregated in numbers so as to most nearly approach a total of 3000 denier. However, this general pattern was diverted from in the case of the nylon/Dacron blends.

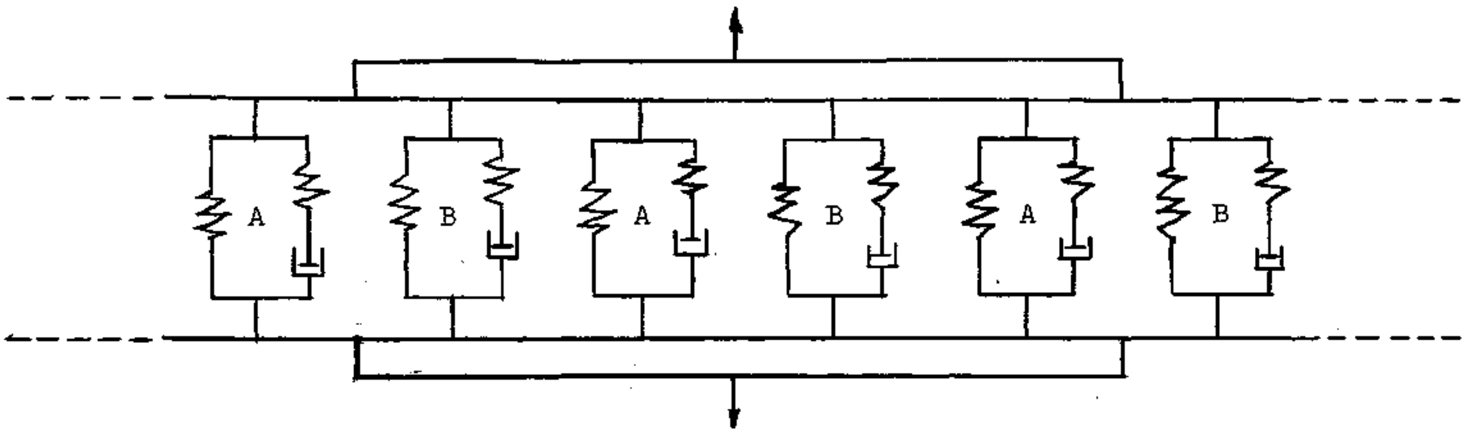
The nylon/Dacron blends in 3000 denier had a breaking strength in excess of 50 pounds. This is over the 50 pound maximum load range of the C tensile cell of the Instron Tester. The C cell was used since it was the only cell to which the Scott CRE Tester pneumatic air jaws had been adapted for use. To alleviate this problem, the nylon/Dacron samples were reduced in total denier size to where their breaking strength would fall within the range of the C tensile cell. The resulting yarns were of approximately 2000 denier.

Consideration was not made of the homogeneity or lack of it in the distribution of blend members composing the model yarn structure. Since no twist was inserted, stress-transfer to surrounding members could not take place upon the rupture of individual ends. Without lateral pressure and transverse forces due to twist, the breaking load of the yarn should be the sum of the breaking loads of the weakest point in each filament.

A graphical representation of the two phases of the research program is presented in Figure 1. Each phase of the research program is pictured with mechanical models utilizing the Maxwell spring and dashpot



Phase 1. Single Ends



Phase 2. Multiple Ends

Figure 1. Graphical Representation of the Research Program

arrangement to characterize the visco-elastic properties of the fibrous high polymers when acting in parallel.

Determination of Physical Properties

Physical properties, such as breaking strength, later converted to tenacity, and breaking elongation, were measured by an Instron Electronic Tensile Tester. The Instron is a constant rate of extension, electronic strain gage type instrument. A Leeds and Northrup high speed recorder supplied a permanent record of the stress-strain curves of all samples tested.

American Society for Testing and Materials standard test procedures were used throughout. A ten inch specimen size was used. Loading at a rate of elongation of 60 percent per minute, the instrument crosshead thus descended at the rate of 6 inches per minute. A sample size of 10 was taken, as test variances were sufficiently low to warrant this. All tests were made under standard conditions of 70° F. and 65% R.H.

During single end investigations, the break sensitivity on the Instron Tester was operting at maximum sensitivity. The break sensitivity attachment will record a break when a stated percentage reduction in load occurs.

However, in multiple end investigations, the nylon did not react to the break sensitivity. This is due to its somewhat higher variation in break elongation than the other fibers employed, causing a stepped breakage rather than a rapid rupture. Backer (76) has discussed this situation at length. Therefore, since the break sensitivity did not function for all cases, it was not employed in the multiple end investigations.

As a result of not using the break sensitivity for the multiple end yarns, elongation measurements on these yarns were not obtainable.

The C tensile load cell was used in all cases. It had maximum load scale ranges of 1, 2, 5, 10, 20, and 50 pounds. The C cell was employed since it was the only cell at the disposal of this research program that had been adapted for use with pneumatic air jaws.

The pneumatic air jaws were obtained from a Scott CRE Tester, and supplied a constant grip of 100 pounds per square inch to the test yarns. To prevent slippage of the yarns in the jaws during the multiple end investigations, it was necessary for the yarn samples to be double wrapped in both the top and bottom jaws.

Significance of Data

All data collected were assumed to be normal and randomly distributed. Due to sufficiently low sample test variances, a sample size of ten was employed.

Hartley's F_{max} Test was used to test the null hypothesis of homogeneity of variance. The null hypothesis was accepted at the $F_{.01}$ level.

An analysis of variance was then performed on the raw data collected for viscose, acetate and nylon. The sources of variation considered were the treatments of combination, percentage and the interaction thereof. The experimental design and all computational formulas used in the analysis of variances are found in Table 8.

For the determination of significance among individual means, Dunnett's t Test (77) for comparing all means with a control was employed. Computational formulas used in these tests are found in Table 9. These and other formulas used in this section come from Winer's test (78).

Computer Aids

Computations of sample means, variances, standard deviations and coefficients of variation were done by the Burroughs Algebraic Computer, Model B-220, at the Rich Electronic Computer Center of the Georgia Institute of Technology.

The computer was also employed for the print-out of the analysis fo variance tables, and where treatments were found to be significant, for the print-out of Dunnett's t Test.

The computer programs used in this study, as designed for the Burroughs-220 computer in ALGOL, are found in Tables 10 and 11.

The word "twist" in the current design of both the analysis of variance and computer program is to permit future investigations where the model yarns have had inserted various levels of twist. The design of this current investigation, although it did not employ twisted yarns, may be readily adapted to the needs of future investigations.

For the purpose of this current investigation, differences between single and multiple end yarns have been considered as differences in twist levels.

CHAPTER IV

DISCUSSION OF RESULTS

The stress-strain curves of the yarns used to compose the model yarn structures in this investigation are pictured in Figure 2.

The stress-strain curves obtained from the blended sample cases were bi-modal curves. There was one mode for each of the two fibers in the bi-component blend. Since each test specimen was of a composite nature, with no twist inserted, a separate mode in the stress-strain curve resulted at the rupture of each member. Only in the case of acetate and nylon, with matched elongations, did a uni-modal stress-strain curve result.

Results could therefore be obtained for the strength of the yarn at the rupture point of either component. These figures were used to calculate the "percent relative blend efficiency" of particular blend combinations and percentages. The blend efficiency is a percentage comparing the strength of the blended model yarn structure at its initial rupture with the maximum possible blend strength that could result if both blend members simultaneously contributed their maximum individual strength potential. Blend efficiency may be viewed simply as a percent utilization of maximum strength potential.

Blend efficiencies for Dacron/viscose, Dacron/acetate, Dacron/nylon, viscose/acetate, viscose/nylon and acetate/nylon, at 25, 50 and 75 percentage levels, may be found in Figure 3.

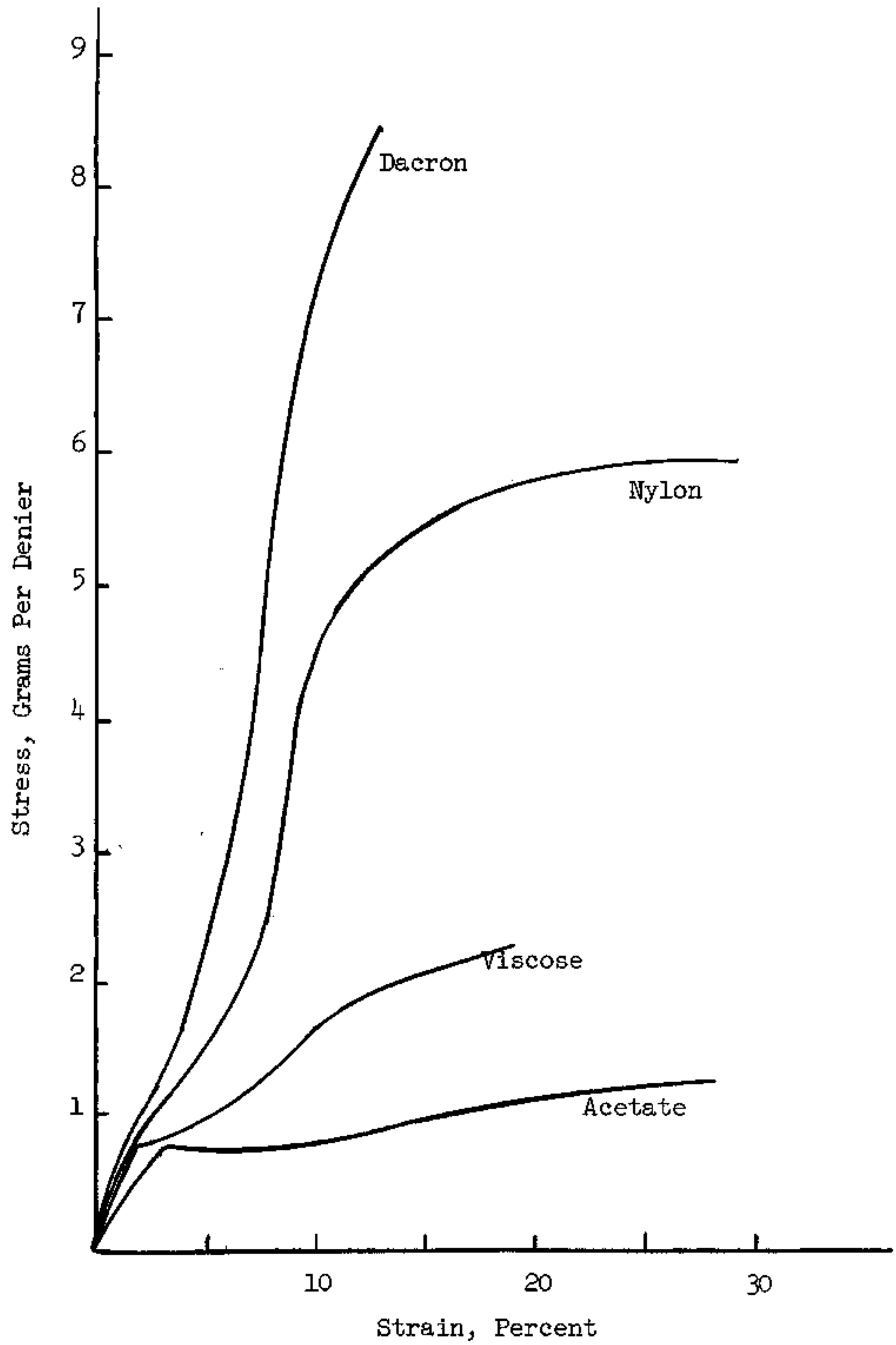


Figure 2. Stress-Strain Curves

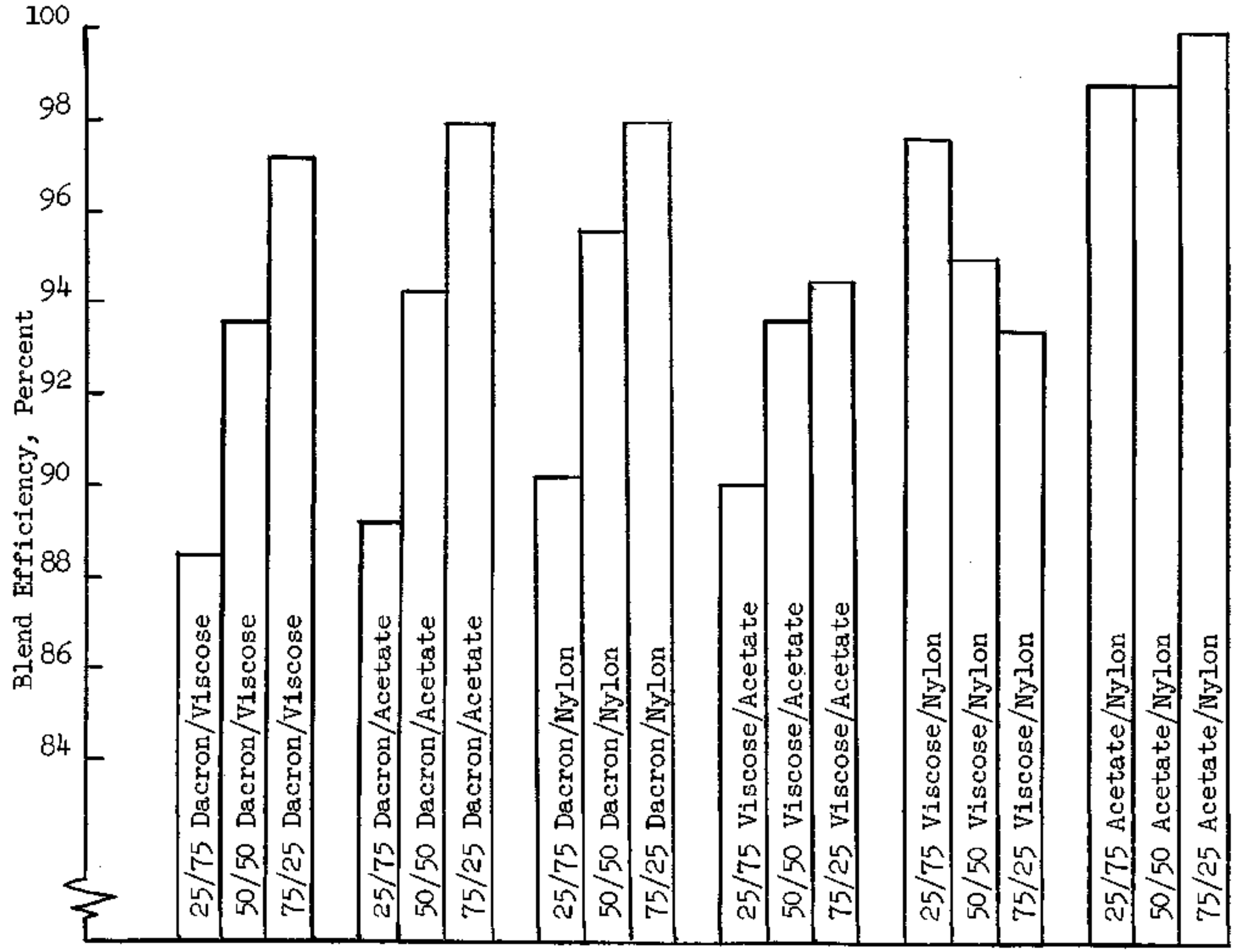


Figure 3. Percent Relative Blend Efficiency of Maximum Individual Contributory Strength

A summary of the blend efficiences for the involved blend combinations, and an average of the three percentage levels for each combination, may be found in Figure 4. The combinations of Dacron/viscose had a blend efficiency of 93.0 percent, Dacron/acetate was 93.9 percent, Dacron/nylon was 92.3 percent, viscose/acetate was 92.7 percent, viscose/nylon was 95.3 percent and acetate/nylon was 99.4 percent.

The combination of acetate/nylon is far more efficient in percent relative blend efficiency than the other combinations tested. This case of acetate/nylon is the only combination where break elongation of the two members was similar, and the resulting blend efficiency approached 100 percent.

Therefore, the matching of break elongations of the components in a composite blend will cause the resultant blend strength to approximate the maximum strength obtainable by a simultaneous contribution of ultimate strength potential of the individual members. At this point, blend efficiency is maximized.

Figure 5 shows the effect of blend percentage on blend efficiency for various blend combinations. All blend combinations affected blend efficiency in a manner related to the relative tenacities of the blending members, provided break elongations were dissimilar.

This is due to the fact that blend efficiency is dependent upon the blend strength at initial rupture, i.e., the rupture point of the lower elongation component in a composite blend. Therefore, the strength of the composite yarn at initial rupture will be the relative strength contribution of the lower elongation member at its maximum possible strain plus the higher elongation member at a fraction of its maximum possible

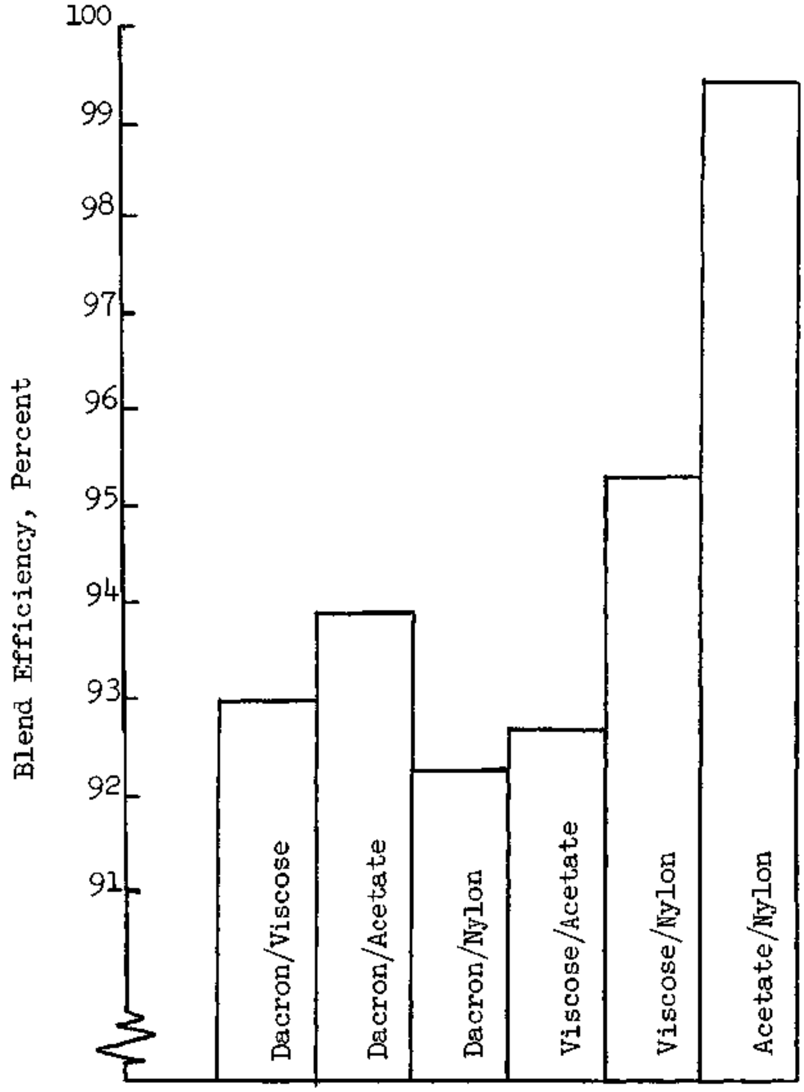


Figure 4. Summary of Percent Relative Blend Efficiencies of Maximum Individual Contributory Strength

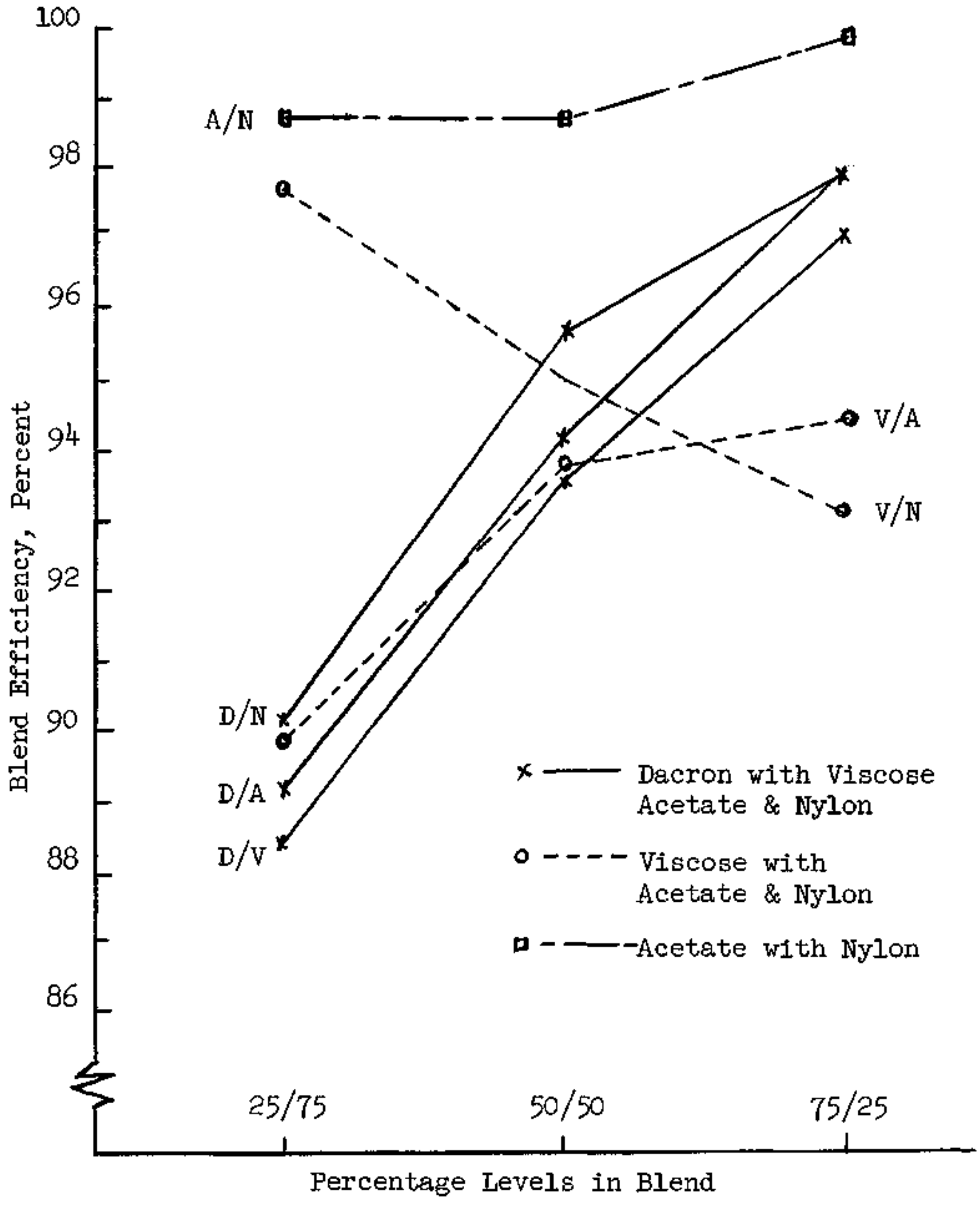


Figure 5. The Effect of Blend Percentage on Blend Efficiency

strain. Changes in the percentage content of the fibers will change the magnitude of the strength at initial rupture by a factor related to the relative tenacities of the blending members. Blend efficiency will accordingly change.

The Dacron had a higher tenacity than any of the other fibrous materials used. Figure 5 clearly shows that with increases in the percentage content of Dacron in its blends with viscose, acetate and nylon, concurrent increases in blend efficiency result. The curves for these combinations are nearly similar in shape and equivalent in magnitude. The blend combinations with Dacron increased in blend efficiency from approximately 89 to 94 to 98 percent with increases in the Dacron content from 25 to 50 to 75 percent.

In the case of viscose/acetate, the viscose had a higher tenacity than acetate. As a result, blend efficiency increased from 90 to 94 percent with increases in the viscose content.

However, in the case of viscose/nylon, the viscose had a tenacity below that of nylon. The blend efficiency curve clearly shows that with increases in the viscose content in combination with nylon, blend efficiency reduces from 98 to 95 to 93 percent.

The case of acetate/nylon was unique in that the break elongation of the two fibers were matched. No premature break could result. Therefore, it would ideally be expected that the blend efficiency curve would be linear, and at maximum efficiency, regardless of the percentage content of the blend members. With increases in the acetate content, the blend efficiency curve was linear at 99 percent from 25 to 50 percent acetate. The curve increased slightly to 100 percent with 75 percent acetate.

It can be concluded, that for composite blends composed of blend members with dissimilar rupture elongations, an increase in the percentage content of the stronger fiber will result in an increase in blend efficiency. For composite blends composed of blend members with similar or matched rupture elongations, the percentage content of the blend members will have no effect upon blend efficiency, which should be at a maximum for this case.

Hamburger (79) has approached the tensile resistance of a composite yarn with similar factors, when he states

> ...that in order to produce a composite yarn the tenacity of which, for all blend percentages, exceeds that of a yarn composed solely of the weaker component, the stress-strain curves of the two materials must be so related that at the ultimate elongation of the weaker component, the load supported by the stronger component must exceed the tenacity of the weaker component.

To translate the results obtained with blend efficiency curves from continuous filament, composite blends to twisted, staple fiber, intimate blends, consideration must be made of the fact that the rupture elongation of the latter will depend upon the rupture elongations of both of the blend members. Also to be considered is inter-fiber slippage as it will depend upon the twist in the yarn (fiber packing density and transverse forces) and the physical dimensions and crimp geometry of the fibers.

One must consider the ultimate end use of the material. This is necessitated since rupture may be viewed in terms of maximum strain reached or maximum stress developed. Both will be affected by a choice of the elongations of the members being blended.

It is believed by the author that these discussions on the strength of a composite yarn may be extended to explain why, in staple blends, the addition in low percentages of certain strong, high elongation fibers to weaker, low elongation fibers, may actually cause a blend strength loss when compared with 100 percent of the latter (80, 81, 82).

It is reasoned, that for the addition of low percentages of the stronger, high elongation fiber, the mutual strain level break of the intimate blend will still remain close to the magnitude of the break elongation of the lower of the two components. At this point of continued low blend elongation, the stronger, high elongation fiber may be at a low enough fraction of its maximum strength that its tenacity could be below that of its blend counterpart. If this is the case, it would be contributing less strength than would an equal amount of its blend counterpart, and a blend strength loss should result.

However, if percentages above from 25 to 50 percent of the stronger, higher elongation component are used, the mutual strain level break of the intimate blend will now be more closely allied to the break elongation of the higher elongation component. At this point of increased break elongation in the blend, when compared with the previous example, the tenacity of the stronger, high elongation fiber should now be of a sufficiently high fraction of its maximum strength that it would be contributing greater strength than an equal amount of its blend counterpart. An increase in blend strength should result.

An analysis of variance was performed on the raw data collected for viscose, acetate and nylon. The sources of variation considered were the effects of combination, percentage, and the interaction of these, i.e., C X P.

Where effects were found to be significant, a Dunnett's t Test for comparing all means with a control was employed to determine significance among individual means.

In all of the ensuing discussions, reports of significance are at the one percent level or less.

Table 1 is the analysis of variance table for viscose and its combination---Dacron/viscose. Significant effects were found for the sources of variation due to combination, percentage, and the interaction of these two.

Table 2 summarizes the tests to determine significance among the individual means. The source of variation due to combination revealed that the tenacity of viscose when in combination with Dacron (2.372 gpd.) was significantly lower than the tenacity of 100 percent viscose (2.448 gpd.)

For the effects due to percentage levels, it was found, for 100 percent viscose and for viscose in combination with Dacron, that the tenacity at the 50/50 level (2.418 gpd.) was significantly greater than the tenacity at the 25/75 level (2.333 gpd.), but significantly less than the tenacity at the 75/25 level (2.479 gpd.).

Investigating the interaction of C X P, it was found that the tenacity of viscose in combination with 25 percent Dacron (2.218 gpd.) was significantly less than the tenacity of 100 percent viscose (2.448 gpd.). The tenacity of viscose in combination with 50 percent Dacron (2.389 gpd.) was also significantly less than viscose while the tenacity of viscose in combination with 75 percent Dacron (2.510 gpd.) was significantly greater than the tenacity of all viscose.

Table 1. Analysis of Variance.
Viscose and Combinations.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	$F_{.01}$
Combination	1	0.08602	0.08602	31.12*	7.16
Percentage	2	0.21497	0.10748	38.89*	5.02
Twist	0	0.0	0.0	0.0	
C X P	2	0.21496	0.10748	38.89*	5.02
C X T	0	0.0	0.0	0.0	
T X P	0	0.0	0.0	0.0	
C X T X P	0	0.0	0.0	0.0	
Within	54	0.14924	0.002763		

*Indicating the effect is significant.

Table 2. Dunnett's t Test. Viscose and Combinations.

Source of Variation				
Source	Treatment	Control	T	$T_{.01}$
Combination	Dacron/Viscose	Viscose	7.89*	2.39
Percentage	25%	50%	7.27*	2.65
Percentage	75%	50%	5.14*	2.65
Percentage	25%	75%	12.41*	2.65
C X P	Dacron/Viscose 25/75	Viscose 100	13.84*	2.95
C X P	Dacron/Viscose 50/50	Viscose 100	3.55*	2.95
C X P	Dacron/Viscose 75/25	Viscose 100	3.72*	2.95

*Indicating the effect is significant.

Table 3 summarizes 99 percent confidence intervals for the difference between treatment and control means which were investigated in Table 2.

Table 4 is the analysis of variance table for acetate and its combinations---Dacron/acetate and viscose/acetate. None of the sources of variation were found to be significant. Therefore, no individual means tests were performed.

Table 5 is the analysis of variance table for nylon and its combinations---Dacron/nylon and viscose/nylon. Significant effects were found for the sources of variation due to combination, percentage, and the interaction of these two.

Table 6 summarizes the tests to determine significance among individual means. The source of variation due to combination revealed that the tenacity of nylon when in combination with Dacron (5.921 gpd.) was significantly greater than the tenacity of 100 percent nylon (5.737 gpd.). However, the tenacity of nylon when in combination with viscose (5.759 gpd.) was not significantly different than all nylon.

For the effects due to percentage levels, it was found that for 100 percent nylon and for nylon in combination with Dacron and viscose, the tenacity at the 50/50 level (5.809 gpd.) was significantly greater than the tenacity at the 25/75 level (5.746 gpd.), but significantly less than the tenacity at the 75/25 level (5.862 gpd.).

Investigating the interaction of C X P, it was found that the tenacity of nylon in combination with 25 percent Dacron (5.810 gpd.) was not significantly different than the tenacity of 100 percent nylon (5.737 gpd.). The tenacity of nylon when in combination with both 50 percent

Table 3. 99% Confidence Intervals for the Difference Between Treatment and Control Means. Viscose and Combinations.

Source of Variation				
Source	Treatment	Control	$\leq$ $(\bar{X}_T - \bar{X}_C)$	$\leq$
Combination	Dacron/Viscose	Viscose	-0.1011	-0.0503
Percentage	25%	50%	-0.1197	-0.0513
Percentage	75%	50%	0.0262	0.0946
Percentage	25%	75%	-0.1801	-0.1117
C X P	Dacron/Viscose 25/75	Viscose 100	-0.2838	-0.1761
C X P	Dacron/Viscose 50/50	Viscose 100	-0.1128	-0.0057
C X P	Dacron/Viscose 75/25	Viscose 100	0.0079	0.1156

Table 4. Analysis of Variance.
Acetate and Combinations

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	$F_{.01}$
Combination	2	0.00691	0.00346	2.10	7.00
Percentage	2	0.00174	0.00087	0.53	7.00
Twist	0	0.0	0.0	0.0	
C X P	4	0.00468	0.00117	0.81	3.59
C X T	0	0.0	0.0	0.0	
T X P	0	0.0	0.0	0.0	
C X T X P	0	0.0	0.0	0.0	
Within	81	0.13357	0.001649		

Table 5. Analysis of Variance.
Nylon and Combinations.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	$F_{.01}$
Combination	2	0.6062	0.3031	60.07*	7.00
Percentage	2	0.2040	0.1020	20.21*	7.00
Twist	0	0.0	0.0	0.0	
C X P	4	0.2110	0.05275	10.45*	3.59
C X T	0	0.0	0.0	0.0	
T X P	0	0.0	0.0	0.0	
C X T X P	0	0.0	0.0	0.0	
Within	81	0.4087	0.005045		

*Indicating the effect is significant.

Table 6. Dunnett's t Test. Nylon and Combinations

Source of Variation				
Source	Treatment	Control	T	$T_{.01}$
Combination	Dacron/Nylon	Nylon	14.18*	2.63
Combination	Viscose/Nylon	Nylon	1.66	2.63
Percentage	25%	50%	4.83*	2.63
Percentage	75%	50%	4.16*	2.63
Percentage	25%	75%	8.98*	2.63
C X P	Dacron/Nylon 25/75	Nylon 100	2.78	3.06
C X P	Dacron/Nylon 50/50	Nylon 100	6.57*	3.06
C X P	Dacron/Nylon 75/25	Nylon 100	38.71*	3.06
C X P	Viscose/Nylon 25/75	Nylon 100	1.61	3.06
C X P	Viscose/Nylon 50/50	Nylon 100	2.42	3.06
C X P	Viscose/Nylon 75/25	Nylon 100	2.06	3.06

*Indicating the effect is significant.

Dacron (5.897 gpd.) and 75 percent Dacron (6.067 gpd.) was significantly greater than the tenacity of all nylon.

The tenacity of 100 percent nylon (5.737 gpd.) was not significantly different than the tenacity of nylon when in combination with 25 percent viscose (5.701 gpd.), 50 percent viscose (5.792 gpd.) or 75 percent viscose (5.784 gpd.).

Table 7 summarizes 99 percent confidence intervals for the difference between treatment and control means which were investigated in Table 6.

An individual means test was to be made on the single end and multiple end tenacity figures to view the results in the light of Peirce's "weak-link" theory (83). However, since results for the progression of increasing the composite size of the specimen from single to multiple end were both increases and decreases in strength, the test was abandoned.

The statistical methods employed in the analysis of these investigations revealed that the addition of up to 50 percent of Dacron to viscose caused a significant strength loss with the viscose. However, the addition of 75 percent of Dacron caused a strength increase with the viscose. It is reasoned that possibly the Dacron, with its high modulus, caused it to carry a greater share of the load. Since the 75 percent Dacron carried a disproportionate share of the load, the viscose was under a lower stress than normal up to the rupture point of the Dacron. Thus, the viscose at its ultimate rupture experienced a strength increase.

The loss of strength to viscose with the addition of up to 50 percent Dacron may be due to some detrimental effect arising from the large disparity between the strengths of Dacron and viscose that may have over-

Table 7. 99% Confidence Intervals for the Difference Between Treatment and Control Means. Nylon and Combinations.

Source of Variation				
Source	Treatment	Control	$\leq$ $(\bar{X}_T - \bar{X}_C)$	$\leq$
Combination	Dacron/Nylon	Nylon	0.1465	0.2212
Combination	Viscose/Nylon	Nylon	-0.0158	0.0589
Percentage	25%	50%	-0.0999	-0.0252
Percentage	75%	50%	0.0166	0.0912
Percentage	25%	75%	-0.1538	-0.0792
C X P	Dacron/Nylon 25/75	Nylon 100	-0.0128	0.1376
C X P	Dacron/Nylon 50/50	Nylon 100	-0.2227	-0.0722
C X P	Dacron/Nylon 75/25	Nylon 100	0.7942	0.9446
C X P	Viscose/Nylon 25/75	Nylon 100	-0.1113	0.0391
C X P	Viscose/Nylon 50/50	Nylon 100	-0.0209	0.1295
C X P	Viscose/Nylon 75/25	Nylon 100	-0.0288	0.1216

come any strength increases from the low Dacron content.

There were no significant strength differences to acetate when blended with Dacron or viscose. It is possible that during the handling of the acetate from floor creel to Instron Tester, a deformation may have been supplied to this relatively weak fiber that cancelled any experimental treatment effects. This permanent deformation would be similar to that which was experienced with acetate during twisting in the early phases of this program.

While the addition of up to 25 percent Dacron to nylon had no significant effect on the strength of the nylon, additions of 50 and 75 percent Dacron did significantly increase the strength of the nylon. As in the case of viscose, the high percentage of Dacron may have been sufficient to carry a greater proportion of the load on the blend at strain levels up to the rupture of the Dacron. The nylon, receiving less stress at the lower strains, was significantly stronger at its rupture elongation.

The modulus of viscose, lower than that of the Dacron, could be the reason that the addition of viscose to nylon had no effect on the strength of the nylon.

For definite answers to the reasons underlying the results obtained with the statistical methods employed, it is suggested that data be replicated for the experimental design to see if the experimental factors considered in this phase of the investigation are stable and will reproduce in a similar manner in the future. It is quite possible that a latent theoretical concept is present, but at the moment is not clearly discernible.

The possibility of the presence of an anomaly should be considered.

Figure 6 summarizes the tenacity measurements for the experimental design. Figure 7 summarizes the variability measurements for the experimental design.

The results obtained using the statistical methods did yield definite statistical significance. However, if being viewed in the light of industrial applications, the magnitude of some of the strength differences may yield only questionable practical significance.

However, the following concept should be given serious consideration as its industrial implications and applications warrant possible further study.

Previous work appearing in the literature, and discussing the realization of obtaining maximum possible strength from a blend of two dissimilar fibers, appears split between matching elongations at rupture of the fibers or the matching of the shape of the stress-strain curve for all strain levels.

It is the belief of this author, and confirmed after assistance from Dennison (84), that the answer to the question of the compatibility of two dissimilar blend members, from a standpoint of stress-strain, should depend upon the ultimate usage of the material.

A determination should be made of the translation of fabric or yarn elongation to fiber elongation. This will supply one with a range around which the maximum fiber elongation is expected during serviceability. It is only up to this particular strain level that the shape of the two materials should be matched. It should be immaterial to concern oneself with the shape of the stress-strain curve at strain levels

		Dacron	Viscose	Dacron/ Viscose	Acetate	Dacron/ Acetate	Viscose/ Acetate	Nylon	Dacron/ Nylon	Viscose/ Nylon
Single End Yarns	50/50	8.464	2.245	2.374	1.234	1.261	1.228	5.919	5.851	5.885
Multiple End Yarns	25/75	7.866*	2.448*	2.218*	1.259*	1.236	1.274	5.737*	5.800	5.701
	50/50	7.866	2.448	2.389	1.259	1.255	1.279	5.737	5.897	5.792
	75/25	7.866	2.448	2.510	1.259	1.270	1.270	5.737	6.067	5.784

*In the multiple end yarns, where no blending was done, data was replicated for all three percentage levels.

Figure 6. Summary of Tenacity Measurements, Grams Per Denier

		Dacron	Viscose	Dacron/ Viscose	Acetate	Dacron/ Acetate	Viscose/ Acetate	Nylon	Dacron/ Nylon	Viscose/ Nylon
Single End Yarns	50/50	1.21	1.53	3.07	1.54	2.99	3.11	1.21	1.63	1.42
Multiple	25/75	0.88*	1.04*	3.02	1.65*	1.60	1.24	0.85*	0.98	1.06
End	50/50	0.88	1.04	2.67	1.65	3.09	1.13	0.85	0.00	0.74
Yarns	75/25	0.88	1.04	3.11	1.65	8.33	0.00	0.85	2.42	1.55

*In the multiple end yarns, where no blending was done, data was replicated for all three percentage levels.

Figure 7. Summary of Variability Measurements, Coefficient of Variation, Percent

above those expected to be a maximum reached by the fiber.

The translation of fabric to fiber properties for continuous filament fabrics will depend a great deal on the crimp interchange and geometry of the fabric. In fabrics composed of staple fiber yarns, an important consideration would also be yarn packing and inter-fiber slippage.

Should translation be in this manner, it is reasonable to assume that in certain apparel fabrics, for example, a particular fabric elongation may be translated to a rather low fiber elongation. It is conceivable, therefore, that in these particular cases, fibers may never reach their break elongation. The fabric wear or breakdown would be a result of individual fiber rupture by a combination of flex and abrasion. The break elongations of the fibers, in this case, should therefore have little effect on the strength of the fabric during usage.

It is also believed by this author that the reason for the presentation, in the literature, of the concept of matching break elongations may be purely one of the economics of the textile industry.

The majority of the yarn and fabric testing instruments in use by the industry today are not sufficiently capable of precisely, efficiently and economically measuring material elongation at a strain level other than rupture. The instruments which are capable of such measurements as suggested by the author are a sizeable investment. As a result, a majority of the smaller firms have not invested in such equipment.

Therefore, since most of the yarn and fabric testing is done at rupture, by tensile type testers, the rupture elongation of the fibers composing the blend, and their strength at rupture, has been taken as a relative measure of the properties of the blended yarn or fabric.

What this author simply questions is; Is it proper to do all fabric tensile testing, and particularly with apparel fabrics, only at rupture elongation? The feasibility of blend strength testing at strain levels below rupture should be given serious consideration.

CHAPTER V

CONCLUSIONS

Blend efficiency has been defined as a percentage comparing the strength of the blended model yarn structure at its initial rupture with the maximum possible blend strength that could result if both blend members simultaneously contributed their maximum individual strength potential.

The matching of the break elongations of the components in a composite blend will cause blend efficiency to be maximized and approach 100 percent.

It may further be concluded that for composite blends composed of blend members with dissimilar rupture elongations, an increase in the percentage content of the stronger fiber will result in an increase in blend efficiency. For composite blends composed of blend members with similar or matched rupture elongations, the percentage content of the blend members will have no effect on blend efficiency, which should be at a maximum for this case.

The discussions on the strength of a composite yarn may be extended to explain why, in intimate, staple blends, the addition in low percentages of certain strong, high elongation fibers, to weaker, low elongation fibers, may actually cause a blend strength loss when compared with 100 percent of the latter.

From the statistical analysis and interpretation of the data obtained from this experiment, the following has resulted:

The addition of up to 50 percent Dacron to viscose caused a significant strength loss with the viscose. However, the addition of 75 percent of Dacron caused a significant strength increase with the viscose.

There were no significant strength differences to acetate when blended with Dacron or viscose.

While the addition of up to 25 percent Dacron to nylon had no significant effect on the strength of the nylon, additions of 50 and 75 percent Dacron did significantly increase the strength of the nylon.

The addition of viscose to nylon had no significant effect on the strength of the nylon.

It is the belief of this author that in designing a blend, the shape of the stress-strain curves of the component fibers should be matched, but only up to the strain level that would be the expected maximum to be reached by the fibers during serviceability. It should be immaterial to concern oneself with the shape of the stress-strain curve above this level.

This author further concludes that the strength testing of blends at strain levels below rupture warrants serious further consideration.

CHAPTER VI

RECOMMENDATIONS

Composite Blends - No Twist

It is recommended that serious consideration be given to the feasibility of the industrial applications of blend testing at strain levels below rupture.

To obtain conclusive evidence of the results arising from employment of the statistical methods in this program, it is suggested that, discounting the presence of an anomaly, data be replicated for the experimental design to determine if the experimental factors considered in this phase of the investigation are stable and will reproduce in a similar manner in the future. It is quite possible that a latent theoretical concept may be present, but at the moment is not clearly discernible.

It is further recommended that these investigations be extended by a similar study using the same fibers with different properties and/or other fibers.

It is suggested that in view of the complexity of the problems investigated by this program, any attempts to translate the results obtained with composite blends to intimate blends may be aided by an examination using dimensional analysis.

While recognizing certain limitations of the method, it may be possible to both reduce the number of parameters involved and to obtain a geometric relationship for the translation.

Intimate Blends - Twisting on a Laboratory Machine

The insertion of twist to multiple end continuous filament structures should be considered as a means of investigating lateral or transverse frictional forces, particularly since they relate to blended yarn strength at strain levels above the break elongation of the lower elongation components. Twist studies would be a much needed continuation to both this present program and to an additional work in cotton/nylon blends.

As a part of the exploratory research in these investigations, some basic studies were initiated into the twisting of the model yarn structures. The result of twisting the model yarn structures would be to produce "intimate" blends as differing from the previously described "composite" blends.

Enough twist would be inserted to expect to create significant lateral or transverse forces. It would be advantageous to investigate twist levels including no twist, and both low and high twist levels. A low twist level would still produce a bi-modal stress-strain curve for the blended yarn, where both blend components maintained their individual break elongation identity. Higher twist levels would produce a coherently twisted structure where the yarn break would be initiated at the weakest point in the yarn and not the individual filaments.

Rather than attempting to twist on a commercial frame the large number of samples included in the experimental design, it was decided to design a laboratory machine that would be suitable for inserting twist into the model yarn structures. The laboratory machine was designed so that it is believed to permit filament migration in twisting, and thus resemble commercially twisted yarn.

The laboratory twisting machine was tested for filament migration by twisting an aggregate of one colored cotton yarn with fifteen uncolored ones. At higher twist levels, the colored yarn was observed to alternately appear and disappear along the length of the twisted yarn specimen. Although no conclusive evidence may be offered, this phenomena led the author to believe that the colored yarn had thus alternately migrated from the outside to the inside of the model yarn aggregate, resulting in filament migration.

The laboratory twisting machine is basically an Alfred Suter Twist Tester, with certain modifications and additions. The twisting head, geared to a revolution counter, and the hand crank mechanism that powers the twisting head are maintained as original equipment.

The changes to the basic structure of the instrument arise in that the retraction measurement is not used. Instead, it is replaced by a double disc compensator type yarn tension apparatus. The double disc compensator was obtained from a warping creel. The double disc compensator was mounted along the twisting axis and supported by a Will chemical laboratory stand. The double discs were weighted down by various numbers of dead weight lug washers.

Ends from many paper tube packages of yarn, and resembling our earlier experimental design, were aggregated together from their support in the hand warping creel as previously used for no twist, multiple end investigations. The aggregate of ends was threaded through a multiple hole, porcelain eyeboard spacer. This spacer was obtained from a warp knitting warper produced by the Cocker Machine and Foundry Co. From the spacer, the ends were placed around the post of the double disc compensator, and along the twisting axis to where it was attached to the twisting head. The length of the twisted specimen was approximately 17 inches.

The eyeboard was employed to control the radial position of the individual ends within the cross section of the model yarn structure.

The use of the double disc compensator, in lieu of a non-slip nip that is originally supplied with the tester, was to allow for filament migration. A non-slip, nip apparatus would not permit outer filaments to migrate, and thus rearrange the distribution of filament lengths. These outer filaments would then have to take the longer, more tortuous path in the twisted helix. As a result, the formation of kinks, straining of the outer filaments and buckling of the center filaments may all occur.

Basic investigations before arrival at the final design of the laboratory twisting machine showed that the use of a non-slip nip apparatus did result in the formation of kinks more rapidly than did use of the double disc compensator.

These basic investigations made use of the Alfred Suter Twist Tester as standard equipment with no modifications. The twisting axis was between the nip on the twisting head and the nip on the yarn retraction measurement apparatus. The nip on the yarn retraction measurement apparatus as well as on the twisting head was of the clamp type and would thus permit no slippage of the filaments between its jaws.

Twisting was attempted with the yarn retraction measuring apparatus acting as a movable trolley and retracting with the insertion of twist. In a separate case, the yarn retraction measuring apparatus was in a fixed position and not allowed to move. Neither case using the yarn retraction measuring apparatus proved as successful as the use of the double disc compensator.

The double disc compensator supplied enough nip on the yarn sample to permit insertion of twist as required, yet still allow some slippage of the filaments between the discs so that a redistribution of filament lengths and filament migration may occur.

A diagram of the final design of the laboratory twisting machine is shown in Figure 8.

However, there are certain variables and factors concurrent with the use of the laboratory twisting machine which warrant study.

It is believed by the author that any migration that may occur in the laboratory twisting machine could be related to the pressure between the discs of the double disc compensator. This pressure is determined by the total weight in lugs used to weight down the discs, and should dictate the amount of filament slippage or filament length redistribution through the double disc compensator. A thorough study of the effects of various pressures between the tensioning discs should be included.

Another effect of the pressure between the tensioning discs will be the amount of tension on the model yarn structure during twisting. As just previously described, higher pressures will reduce filament slippage and thus may reduce filament migration. However, Kilby's compression theory (85) might lead one to believe that higher pressures on the tensioning discs may cause increased migration upon removal of tension. The

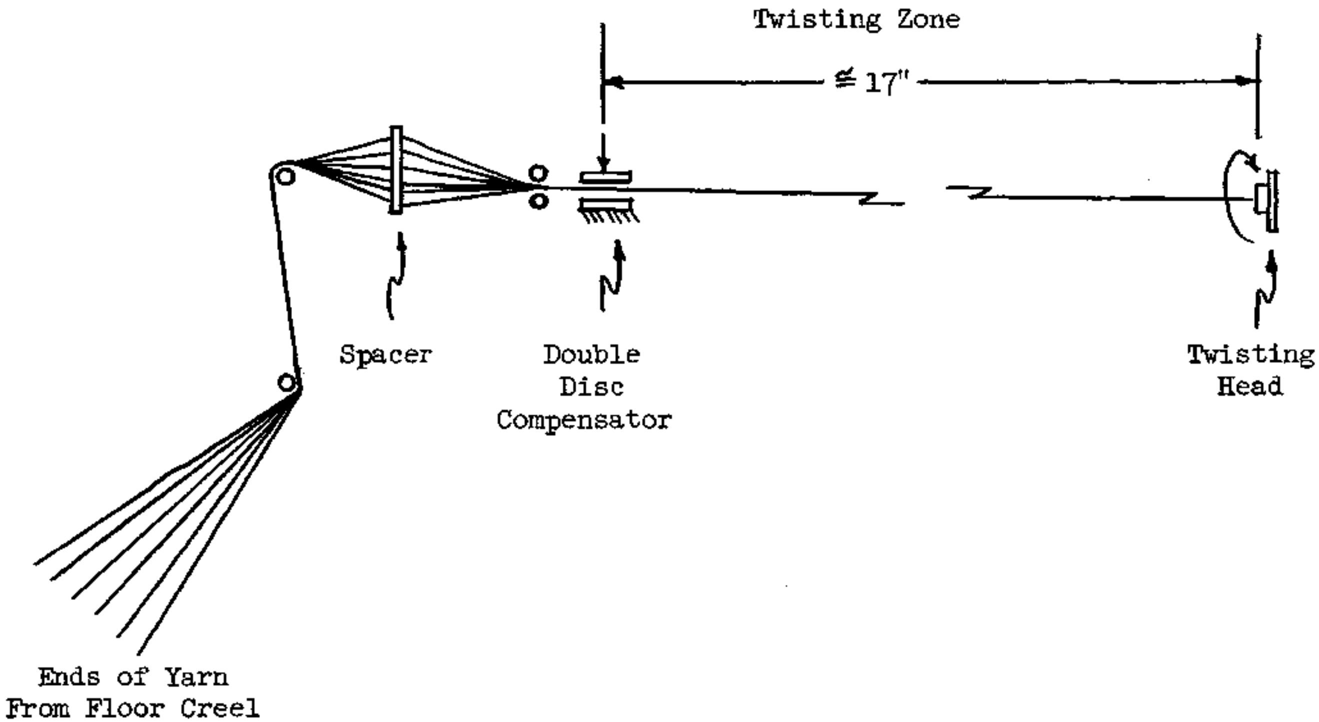


Figure 8. Laboratory Twisting Machine

dependence of filament migration upon the removal of tension is discussed by Backer and Hearle _et al_. (86); "this confirms the suggestion that migration of a component from the central position to the outside (of the yarn) is possible only when it becomes slack". Also, "The theoretical and experimental curves are in reasonable agreement, and this confirms the essential truth of the postulate that migration only occurs when the center ply becomes slack and buckles". Migration should therefore be tested both in and out of the twisting machine.

Consideration should be made of the differences that may result if samples were tested immediately upon removal from the twisting machine or if they were allowed to relax for a stated time period.

Backer and Hearle _et al_. (87) show that the shape of the fiber formed yarn aggregate entering the twisting zone will affect the fiber distribution within the yarn structure. The effects of varying filament distribution should be related to the nature of the filament migration and the properties of the aggregated model yarn.

Use was made of a porcelain eyeboard spacer to control both the shape of the yarn as it entered the twisting zone and the radial positioning of the blend members within the cross-section of the yarn. Although a cylindrical pattern was used when threading ends in the spacer, the nip on the yarn by the tensioning discs and at the twisting head may cause twisting of the model yarn in a ribbon shape rather than as a cylinder. Backer and Hearle _et al_. (88) discuss the effects of ribbon twisting on yarn properties.

The visual method previously described for testing filament migration in the laboratory twisting machine by using one colored yarn with many uncolored ones must be viewed in an expanded light. It now appears obvious that the spatial relationship of one colored yarn incorporated into an uncolored model yarn and twisted on the laboratory twisting machine will be affected by the initial radial positioning of that colored yarn as it enters the twisting zone and by the shape of the cross section of the model yarn.

The spacer also serves the purpose of controlling the radial positioning of each blend component in relation to the other within the cross section of the yarn. The ends may be dispersed within the spacer as a honogeneous blend, or one component may be positioned to enter the twisting zone in a particular area of the model yarn cross section. For example, the low elongation component, instead of being homogeneously dispersed among the high elongation component, may find itself preferentially positioned.

The low elongation component may be placed to receive the maximum pressures developed within the twisted model yarn structure. It was previously believed that this would be the center of the yarn, but Backer and Hearle *et al*. (89) state that "Maximum density of packing is not at the center, but surprisingly about three-fifths of the way out from the center".

Attention must also be paid to the increase in tension with the progression of twisting. At higher twist levels, the tension may reach such proportions as to cause permanent deformation to certain samples. This is similar to what had previously been experienced by this program with high twisting tensions on viscose. Acetate will also be susceptible to such deformations.

There is the alternative that twisting may progress with a steady rise in filament tension, or that the twisting tension may be equalized for all twist levels by adjusting the pressure between the tensioning discs on the double disc compensator.

If the original experimental design is followed as outlined in this program, some arrangement must be made for the use of a parameter to supply a standard maintenance of equivalent load so that test samples may be compared. This is necessitated by the fact that fibers of different diameters were used, which made it impossible to maintain the same diameter in the model yarn structure for all test cases.

One suggested parameter is Schwarz's (90) formula for helix angle, used in its modified form as obtained from Platt (91). The helix angle is the twist angle across the yarn. Helix angle may be used since the tensile resistance of the yarn will be related to the cosine squared of the helix angle.

The formula for helix angle is:

$$\text{Tan } \theta = \pi KDN, \text{ where}$$

θ = external helix angle

K = constant that relates filament diameter to yarn diameter

D = yarn diameter

N = number of turns of twist per unit length.

K is assumed to be insignificant if the filament diameter is small compared to the yarn diameter. Backer and Hearle _et al_. (92) discuss the effects when K is significant.

Tangent Θ would be held constant, and the equation would be used to supply the number of turns per unit length that would be inserted into the model yarn by the laboratory twisting machine. The diameters of the yarns may be calculated, or else measured by microscopic techniques.

During twisting on the laboratory machine, an AO Spencer stereo bi-ocular microscope was employed to observe the insertion of twist, formation of the helix angle and also to note the formation of kinks or strained filaments.

Following twisting, a comparison should be made of helix angle measurements both as theoretically calculated and experimentally measured. There is available for this purpose a Russian toolmaker's microscope in the optical laboratory of the Hinman Research Building. The microscope is equipped with an eyepiece containing rotating crosshairs. The crosshairs are parallelized with the fiber axis, and then rotated to the external helix angle across the surface of the yarn. An auxiliary gauge, graduated in minutes of a degree, records the angle through which the crosshairs are rotated.

Another parameter instead of helix angle which may prove suitable is the concept of a similar twist factor or twist multiple, provided that changes in yarn diameter be taken into account.

$$\text{twist factor} = \text{turns per cm.} \times \sqrt{\text{tex}}$$

$$\text{twist factor} = \text{turns per inch} \times \sqrt{\text{denier}}$$ after Alexander and Sturley

$$\text{twist multiple} = \frac{\text{turns per inch}}{\sqrt{\text{count}}}$$

With the aid of Backer's (93) assistance, it appears reasonable that yarns of like material, diameter and outside helix angle may be compared on a basis of breaking strength. If fiber packing density alone accounts for a difference in yarn diameters, the tenacities should still be the same.

However, in the case of one material being blended with other materials, maintaining similar yarn diameters and outside helix angles, some other factors must be considered. Consideration should be given to fiber configuration and particularly crimp geometry. Dennison (94), in addition to Backer, has noted the importance of investigating fiber crimp differences in blend components.

It should be interesting to compare test results of the model yarn structure twisted on the laboratory twisting machine with similar yarns twisted on a commercial Brownell of Haskell-Dawes twister.

Fabric Situation

Backer (95) and Hoffman (96) have expressed the belief that the magnitude of lateral or transverse frictional forces found in twisted yarns may be materially increased in similar yarns introduced into a fabric structure. This is a result of the compressive nature of the forces on the yarns at the intersections of warp and filling.

At the suggestion of Hoffman, a device may be designed to simulate the fabric situation. The design would consist of interweaving test yarns around teflon coated steel rods. The rods would be supported at their ends in a frame. The frame would be taken directly to the Instron Tester where the yarns would be elongated to break. The compressive forces between yarn and rods should be representative of the crossings of warp and filling yarns in a fabric structure.

The rods may be either fixed or free to rotate. They may be placed in line or slightly offset. The diameter of the rods, the distance between rods and the number of rods used should all be chosen to most closely resemble the fabric situation. It is suggested that the rods be teflon coated to reduce any frictional effects between test yarn and rods.

Similar yarns, tested both solely in the yarn form and in this fabric simulating device, should offer a comparison of the differences in magnitude of lateral or transverse frictional forces developed within yarns, and in these yarns when subjected to fabric geometry.

Fiber Crimp Differences

Dennison (97) and Backer (98) have recently commented on what is believed to be the important role played by the geometry of fiber configuration, i.e., fiber crimp, upon yarn strength.

It should be worthwhile to develop such a program where different types of fiber crimp would be built into the same material. Similarly spun yarns would then be compared for differences in strength.

The program may be extended to include blended yarns where the crimp in one component would remain constant while the crimp in the other component would be varied.

APPENDICES

APPENDIX A

INTERPRETATION OF DATA

			Dacron*	Viscose*	Dacron/ Viscose	Acetate*	Dacron/ Acetate	Viscose/ Acetate	Nylon*	Dacron/ Nylon	Viscose/ Nylon	Acetate/ Nylon
			C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
T_1 Single End Yarns	50/50	P_0										
T_2 Multiple End Yarns	25/75	P_1										
	50/50	P_2										
	75/25	P_3										

*When only one fiber is shown, i.e., not in a blend, the percentage figures denote a blend of the fiber with itself.

Figure 9. The Experimental Design

Table 8. The Design for Analysis of Variance

All factors were fixed. Equal cell frequencies were maintained.

C = Combination
T = Twist
P = Percentage
n = Number of members in each cell

I = (1, 2, 3... L) where L is the number of combinations.
J = (1, 2... N) where N is the number of twist levels.
K = (1, 2... Z) where Z is the number of percentage levels.
M = (1, 2... S) where S is the number in each cell.

Source of Variation	Degrees of Freedom	Expected Mean Square
Combination	(C - 1)	$\sigma^2_E + nPT\sigma^2_C$
Percentage	(P - 1)	$\sigma^2_E + nCT\sigma^2_P$
Twist	(T - 1)	$\sigma^2_E + nCP\sigma^2_T$
C X P	(C - 1)(P - 1)	$\sigma^2_E + nT\sigma^2_{C \times P}$
C X T	(C - 1)(T - 1)	$\sigma^2_E + nP\sigma^2_{C \times T}$
P X T	(P - 1)(T - 1)	$\sigma^2_E + nC\sigma^2_{P \times T}$
C X P X T	(C - 1)(P - 1)(T - 1)	$\sigma^2_E + n\sigma^2_{C \times P \times T}$
Within	(C)(P)(T)(n - 1)	σ^2_E

(Continued)

Table 8. (Continued)

Formulas for Squares

(1) $(\sum X_{IJKM})^2/CPTn$

(2) $\sum(X^2_{IJKM})$

(3) $\sum(C_I)^2/PTn$

(4) $\sum(T_J)^2/CPn$

(5) $\sum(P_K)^2/CTn$

(6) $\sum(CT_{IJ})^2/Pn$

(7) $\sum(CP_{IK})^2/Tn$

(8) $\sum(PT_{JK})^2/Cn$

(9) $\sum(CPT_{IJK})^2/n$

(Continued)

Table 8. (Concluded)

Sum of Squares - Computational Formulas

Combination	(3) - (1)
Percentage	(5) - (1)
Twist	(4) - (1)
C X P	(7) - (3) - (5) + (1)
C X T	(6) - (3) - (4) + (1)
P X T	(8) - (4) - (5) + (1)
C X P X T	(9) - (6) - (7) - (8) + (3) + (4) + (5) - (1)
Within	(2) - (9)
Total	(2) - (1)

Significance Computations

Mean Square = Sum of Squares ÷ Degrees of Freedom

F = Mean Square Treatment ÷ Mean Square Within

Table 9. The Design of Dunnett's t Test for Comparing All Means With a Control

$$t = \frac{(X_T - X_C)}{\sqrt{\frac{2MSE}{CPTn}}}$$

Where: X_T = Treatment mean

X_C = Control mean

MSE = Mean square error within

$$\text{Range} = \left(\sqrt{\frac{2MSE}{CPTn}}\right)\left(t_{(1 - \frac{\alpha}{2})}\right)$$

$$\text{Confidence Interval}_{(1 - \alpha)} = (X_T - X_C) \pm \text{Range}$$

Table 10. The Computer Program for Analysis of Variance, Designed for Burroughs-220 Algebraic Computer in ALGOL

```
2 COMMENT ANALYSIS OF VARIANCE FOR A RESEARCH PROGRAM IN TEXTILES $
2 INTEGER I,J,K,   M,L,Z,S,N,DF1,DF2,DF3,DF4,DF5,DF6,DF7,DF8 $
2 ARRAY X(10,3,3,10), P(10,3,3), Q(10,3,3), R(10,3,3),H(10,3,3),
2 CR(10,3), CR2(10,3), V(10), CRM(10,3), T(10,3,3),CV(10,3,3) $
2 INPUT SMS (L,N,Z,S,FOR I=(1,1,L)$FOR J=(1,1,N)$FOR K=(1,1,Z) $
2 FOR M=(1,1,S)$X(I,J,K,M)) $
2 FORMAT FMT1 (B10,*CELL*,B23,*MEAN*,B20,*VARIANCE*,B20,
2 *STD DEVIATION*,B5,*CV*,W3) $
2 FORMAT FMT2 (B8,I2,I2,I2,B17,X12.6,B13,X12.6,B18,X12.6,B5,X12.6,WO) $
2 OUTPUT OUT2 ( FOR I=(1,1,L)$ FOR J=(1,1,N)$ FOR K=(1,1,Z)$ (I,J,K,
2 T(I,J,K), R(I,J,K), H(I,J,K),CV(I,J,K)))  $
2 FORMAT FMT3 (B34,*ANALYSIS OF VARIANCE*,W4,*SOURCE OF VARIATION*,
2 B5,*DF*,B4,*SUM OF SQUARES*,B6,*MEAN SQUARE*,B10,*F*,W4)  $
2 FORMAT FMT4 (B7,*COMBINATION*,B5,I3,B4,X14.6,B6,X11.6,B5,X12.6,W2,
2 B7,*PERCENTAGE*,B6,I3,B4,X14.6,B6,X11.6,B5,X12.6,W2,
2 B7,*TWIST*,B11,I3,B4,X14.6,B6,X11.6,B5,X12.6,W2,
2 B7,*C X P*,B11,I3,B4,X14.6,B6,X11.6,B5,X12.6,W2,
2 B7,*C X T*,B11,I3,B4,X14.6,B6,X11.6,B5,X12.6,W2,
2 B7,*T X P*,B11,I3,B4,X14.6,B6,X11.6,B5,X12.6,W2,
2 B7,*C X T X P*,B7,I3,B4,X14.6,B6,X11.6,B5,X12.6,W2,
2 B7,*WITHIN*,B10,I3,B4,X14.6,B6,X11.6,B5,W2) $
2 OUTPUT OUT4 (DF1,COMB,MC,F1,DF2,PERC,MP,F2,DF3,TWT,MT,F3,DF4,COMPER,
2 MCP,F4,DF5,COMTWT,MCT,F5,DF6,PERTWT,MPT,F6,DF7,COMTWTPER,
2 MCPT,F7,DF8,WITHIN,MW)  $
2 FORMAT FMT5A (B20,*MEANS OF C X T CELLS*,W4,B10,*CELL LOCATION*,
2 B13,*MEAN*,W2)  $
2 FORMAT FMT5 (B13,I2,I2,B15,X11.6,WO)    $
2 OUTPUT OUT5 (For I= (1,1,L)$FOR J = (1,1,N)$ (I,J,CRM(I,J)))$
2 FORMAT FMT6A (B20,*MEANS OF C X P CELLS*,W4,B10,*CELL LOCATION*,
2 B13,*MEAN*,W2)   $
2 FORMAT FMT6 (B13,I2,I2,B15,X11.6,WO)    $
2 OUTPUT OUT6 (FOR I= (1,1,L)$FOR K = (1,1,Z)$  (I,K,CRM(I,K)))    $
2 FORMAT FMT7A (B20,*MEANS OF T X P CELLS*, W4,B10,*CELL LOCATION*,
2 B13,*MEAN*,W2)    $
2 FORMAT FMT7 (B13,I2,I2,B15,X11.6,WO)   $
2 OUTPUT OUT7 (FOR J = (1,1,N)$FOR K = (1,1,Z)$ (J,K,CRM(J,K)))   $
2 FORMAT FMT8A (B20,*MEANS OF COMBINATIONS*,W4,B10,*CELL LOCATION*,
2 B20,*MEAN*,W2)   $
2 FORMAT FMT8(B17,I2,B19,X11.6,WO)   $
2 OUTPUT OUT8 (I,TS)   $
2 FORMAT FMT9A (B20,*MEANS OF TWISTS*,W4,B10,*CELL LOCATION*,
2 B20,*MEAN*,W2)    $
2 FORMAT FMT9 (B17,I2,B19,X11.6,WO)    $
```

(Continued)

Table 10. (Continued)

```
2 OUTPUT OUT9 (J,TS)   $
2 FORMAT FMT10A (B20,*MEANS OF PERCENTAGES*,W4,B10,*CELL LOCATION*,
2 B20,*MEAN*,W2)   $
2 FORMAT FMT10 (B17,I2,B19,X11.6,W0)     $
2 OUTPUT OUT10 (K,TS)   $
2 START.. READ ($$ SMS)      $
2 WRITE ($$FMT1)    $
2 FOR I=(1,1,L)$FOR J=(1,1,N)$FOR K=(1,1,Z)   $
2 BEGIN SUM2 = 0.0         $
2 FOR M = (1,1,S)          $
2 BEGIN SUM2 = SUM2 + X(I,J,K,M)   $    END      $
2 Q(I,J,K) = SUM2    $
2 T(I,J,K) = Q(I,J,K)/S   $         END    $
2 FOR I=(1,1,L)$FOR J=(1,1,N)$FOR K=(1,1,Z)     $
2 BEGIN     SUM1=0.0      $
2 FOR M = (1,1,S)     $
2 BEGIN SUM1 = SUM1 + X(I,J,K,M)    * 2.0  $END$
2 P(I,J,K) = SUM1   $   END     $
2 FOR I=(1,1,L)$FOR J=(1,1,N)$FOR K=(1,1,Z)      $
2 BEGIN R(I,J,K) = (P(I,J,K)    -  ((Q(I,J,K))*2.0/S))/(S-1.0)    $
2 H(I,J,K)= SQRT(R(I,J,K)) $
2 CV(I,J,K) = ((H(I,J,K)/T(I,J,K)).(100.0))    $   END   $
2 WRITE ($$OUT2,FMT2)    $
2 WRITE ($$FMT5A)    $
2 SUMCR2 = 0.0     $
2 FOR I=(1,1,L)$ FOR J=(1,1,N)    $
2 BEGIN SUMIJ=0.0$  FOR K=(1,1,Z)    $
2 BEGIN SUMIJ = SUMIJ + Q(I,J,K)$    END    $
2 CR(I,J)=SUMIJ   $        CRM(I,J) = CR(I,J) / S.Z   $
2 BEGIN CR2(I,J)=CR(I,J)*2      $
2 SUMCR2=SUMCR2 + CR2(I,J)$    END$    END   $
2 CT2 = SUMCR2        $
2 WRITE ($$ OUT5,FMT5)    $
2 WRITE ($$FMT6A)      $
2 SUMCR2=0.0       $
2 FOR I=(1,1,L)$ FOR K=(1,1,Z)     $
2 BEGIN SUMIJ=0.0$   FOR J=(1,1,N)    $
2 BEGIN SUMIJ=SUMIJ + Q(I,J,K)$     END     $
2 CR(I,K)=SUMIJ    $          CRM(I,K) = CR(I,K)/S.N    $
2 BEGIN CR2(I,K)=CR(I,K)*2     $
2 SUMCR2=SUMCR2 + CR2(I,K)$     END$      END$
2 WRITE ($$OUT6,FMT6)     $
2 WRITE ($$FMT7A)      $
```

(Continued)

Table 10. (Continued)

```
2 CP2 = SUMCR2     $
2 SUMCR2=0.0     $
2 FOR J=(1,1,N)$  FOR K=(1,1,Z)  $
2 BEGIN SUMIJ=0.0$  FOR I=(1,1,L)    $
2 BEGIN SUMIJ = SUMIJ + Q(I,J,K)  $   END   $
2 CR(J,K) = SUMIJ    $   CRM(J,K) = CR(J,K)/S.L     $
2 BEGIN CR2(J,K) = CR(J,K)*2   $
2 SUMCR2=SUMCR2 + CR2(J,K)$   END$    END$
2 WRITE ($$OUT7,FMT7)    $
2 WRITE ($$FMT8A)    $
2 TP2 = SUMCR2    $
2 SUMX2=0.0    $
2 FOR I=(1,1,L)$ FOR J=(1,1,N)$ FOR K=(1,1,Z)    $
2 BEGIN SUMX2=SUMX2 + P(I,J,K) $ END $
2 CPT2=0.0$  GRSUM=0.0    $
2 FOR I=(1,1,L)$ FOR J=(1,1,N)$ FOR K=(1,1,Z)    $
2 BEGIN BEGIN CPT2 = CPT2 + Q(I,J,K)*2.0 $   END  $
2 BEGIN GRSUM = GRSUM + Q(I,J,K)  $ END $ END $
2 SM = 0.0    $
2 FOR I = (1,1,L)   $
2 BEGIN SUMZ = 0.0$ FOR J = (1,1,N)$ FOR K = (1,1,Z)    $
2 BEGIN SUMZ = SUMZ + Q(I,J,K)   $    END     $
2 TS = SUMZ/(N.Z.S)   $
2 WRITE ($$OUT8,FMT8)   $
2 V(I) = SUMZ*2     $
2 SM = SM + V(I)  $   END     $
2 WRITE ($$FMT9A)    $
2 C2 = SM   $
2 SM = 0.0  $
2 FOR J = (1,1,N)    $
2 BEGIN SUMZ = 0.0$   FOR I = (1,1,L)$    FOR K = (1,1,Z)   $
2 BEGIN SUMZ = SUMZ + Q(I,J,K)   $    END     $
2 TS = SUMZ/(L.Z.S)   $
2 WRITE ($$OUT9,FMT9)   $
2 V(J) = SUMZ*2    $
2 SM = SM + V(J)   $   END   $
2 WRITE ($$FMT10A)      $
2 T2 = SM    $
2 SM = 0.0    $
2 FOR K = (1,1,Z)    $
2 BEGIN SUMZ = 0.0$   FOR I = (1,1,L)$   FOR J = (1,1,N)    $
2 BEGIN SUMZ = SUMZ + Q(I,J,K)   $    END    $
2 TS = SUMZ/(L.N.S)   $
```

(Continued)

Table 10. (Concluded)

```
2 WRITE ($$OUT10,FMT10)   $
2 V(K) = SUMZ*2     $
2 SM = SM + V(K)  $   END   $
2 P2 = SM   $
2 WRITE ($$FMT3)    $
2 COMB = (C2/S.Z.N) - (GRSUM*2.0 /S.Z.L.N)   $
2 PERC = (P2/S.L.N) - (GRSUM*2.0/S.Z.L.N)   $
2 TWT = (T2/S.L.Z) - (GRSUM*2.0/S.Z.L.N)    $
2 COMPER = (CP2/S.N) + (GRSUM*2.0/S.Z.L.N) - (P2/S.L.N) -
2 (C2/S.Z.N)  $
2 COMTWT = (CT2/S.Z) - (C2/S.Z.N) -(T2/S.L.Z)+
2 (GRSUM*2.0 /S.L.Z.N)  $
2 PERTWT = (TP2/S.L) - (T2/S.L.Z) - (P2/S.L.N)+
2 (GRSUM*2.0/S.Z.L.N)  $
2 COMTWTPER = (CPT2/S) - (CT2/S.Z) - (CP2/S.N) -
2 (TP2/S.L) + (C2/S.Z.N) + (T2/S.L.Z)+
2 (P2/S.L.N) - (GRSUM*2.0/S.L.Z.N)   $
2 WITHIN = SUMX2 - (CPT2/S)   $
2 MC = COMB/(L-1)    $
2 MP = PERC/(Z-1)    $
2 MT = TWT/(N-1)     $
2 MCP = COMPER/(L-1).(Z-1)    $
2 MCT = COMTWT/(L-1).(N-1)    $
2 MPT = PERTWT/(Z-1).(N-1)    $
2 MCPT = COMTWTPER/(L-1).(N-1).(Z-1)  $
2 MW = WITHIN/L.Z.N. (S-1)  $
2 F1 = MC/MW    $
2 F2 = MP/MW    $
2 F3 = MT/MW    $
2 F4 = MCP/MW    $
2 F5 = MCT/MW    $
2 F6 = MPT/MW    $
2 F7 = MCPT/MW    $
2 DF1 = L-1    $
2 DF2 = Z-1    $
2 DF3 = N-1    $
2 DF4 = (L-1).(Z-1)    $
2 DF5 = (L-1).(N-1)    $
2 DF6 = (Z-1).(N-1)    $
2 DF7 = (L-1).(N-1).(Z-1)    $
2 DF8 = L.Z.N. (S-1)    $
2 WRITE ($$OUT4,FMT4)   $
2 GO TO START    $
2 FINISH   $
5 2 2 3 10
5 2.192 2.238 2.238 2.238 2.238 2.298 2.298 2.268 2.208 2.238
```

Table 11. The Computer Program for Dunnett's t Test, Designed for the Gurroughs B-220 Algebraic Computer in ALGOL

```
2 COMMENT DUNNETTS T TEST FOR COMPARING MEANS  $
2 INTEGER I,J,K,L,V,M    $
2 INPUT DATA (XT,XC,MSE,C,P,T,N,I,J,K,L,V,M,B)    $
2 FORMAT FMT1 (B1,*TCELL*,B2,*CNCELL*,B9,*TREATMENT MEAN*,B8,
2 *CONTROL MEAN*,B10,*TT*,B13,*B*,B11,*CONFIDENCE INTERVAL*,W2)  $
2 FORMAT FMT2 (3I2,B2,3I2,X22.6,X20.6,X16.6,X14.6,X15.6,X12.6,W0)  $
2 OUTPUT ANS (I,J,K,L,V,M,XT,XC,TT,B ,E2,E1)   $
2 WRITE ($$FMT1)  $
2 SS.. READ ($$DATA)  $
2 T1 = (XT - XC)   $
2 D3 = ((2.0).(MSE))   $
2 D4 = (C.P.T.N)    $
2 A = (D3/D4)    $
2 D1 = (SQRT(A))   $
2 TT = (T1/D1)    $
2 F1 = ((D1).(B))   $
2 E1 = (T1 + F1)    $
2 E2 = (T1 - F1)    $
2 WRITE ($$ANS,FMT2)   $
2 GO TO SS   $
2 FINISH    $
5 2.372883 2.346600 0.003005 1.0 3.0 2.0 10.0 2 0 0 1 0 0 2.66
```

Table 12. Operational Data. Whitin Model B Novelty Twister

$$\text{Twist Constant} = \frac{32 \text{ X } 126 \text{ X } 100 \text{ X } 112 \text{ X } 8}{\text{D X } 45 \text{ X TG X } 46 \text{ X } 1\ 11/16 \text{ X } 3.14 \text{ X } 1\ 1/2}$$

= 29,150 Top Line; 245 Bottom Line

If higher twists are desired, the twist constant may be increased by replacing the ratio of crown gear to front roll gear from 112/46 as above to 138/20.

$$\frac{\text{Twist Constant}}{\text{Turns per Inch}} = \text{Teeth in Twist Gear}$$

$$\frac{245}{5.0 \text{ TPI}} = 49 \text{ Teeth}$$

APPENDIX B

TABULATION OF DATA

Table 13. Percentage and Denier of Single End Yarns

Fibers	Approximate Percentage	Individual Denier	Total Denier	Exact Percentage
Dacron	100	220	220	100.0
Viscose	100	150	150	100.0
Dacron	50	220	370	59.5
Viscose	50	150		40.5
Acetate	100	150	150	100.0
Dacron	50	220	370	59.5
Acetate	50	150		40.5
Viscose	50	150	300	50.0
Acetate	50	150		50.0
Nylon	100	200	200	100.0
Dacron	50	220	420	52.4
Nylon	50	200		47.6
Viscose	50	150	350	42.8
Nylon	50	200		57.2
Acetate	50	150	350	42.8
Nylon	50	200		57.2

Table 14. Percentage and Denier of Multiple End Yarns

Fibers	Approximate Percentage	Individual Denier	No. of Ends	Component Denier	Total Denier	Exact Percentage
Dacron	100	220	10	2200	2200	100.0
Viscose	100	150	15	2250	2250	100.0
Dacron	25	220	4	880	2980	27.5
Viscose	75	150	14	2100		70.5
Dacron	50	220	7	1540	3040	50.7
Viscose	50	150	10	1500		49.3
Dacron	75	220	10	2200	2950	74.7
Viscose	25	150	5	750		25.3
Acetate	100	150	15	2250	2250	100.0
Dacron	25	220	4	880	2980	29.5
Acetate	75	150	14	2100		70.5
Dacron	50	220	7	1540	3040	50.7
Acetate	50	150	10	1500		49.3
Dacron	75	220	10	2200	2950	74.7
Acetate	25	150	5	750		25.3
Viscose	25	150	5	750	3000	25.0
Acetate	75	150	15	2250		75.0
Viscose	50	150	10	1500	3000	50.0
Acetate	50	150	10	1500		50.0
Viscose	75	150	15	2250	3000	75.0
Acetate	25	150	5	750		25.0
Nylon	100	200	11	2200	2200	100.0
Dacron	25	220	2	440	1840	23.9
Nylon	75	200	7	1400		76.1
Dacron	50	220	5	1100	2100	52.4
Nylon	50	200	5	1000		47.6
Dacron	75	220	6	1320	1720	76.7
Nylon	25	200	2	400		23.3

(Continued)

Table 14. (Concluded)

Fibers	Approximate Percentage	Individual Denier	No. of Ends	Component Denier	Total Denier	Exact Percentage
Viscose	25	150	5	750	2950	25.4
Nylon	75	200	11	2200		74.6
Viscose	50	150	10	1500	2900	51.7
Nylon	50	200	7	1400		48.3
Viscose	75	150	15	2250	3050	73.8
Nylon	25	200	4	800		26.2
Acetate	25	150	5	750	2950	25.4
Nylon	75	200	11	2200		74.6
Acetate	50	150	10	1500	2900	51.7
Nylon	50	200	7	1400		48.3
Acetate	75	150	15	2250	3050	73.8
Nylon	25	200	4	800		26.2

Table 15. Single End Blend Strengths.
100% Dacron

	Strength, Lbs.	Elongation, Percent	Tenacity, Gms./Denier
	4.15	13.8	8.556
	4.10	13.2	8.453
	4.10	12.6	8.453
	4.10	13.8	8.453
	4.00	12.0	8.247
	4.10	13.2	8.453
	4.10	10.8	8.453
	4.10	12.0	8.453
	4.10	13.2	8.453
	4.20	12.6	8.659
Mean	4.105	12.72	8.464
Coefficient of Variation, Percent			1.21

Table 16. Single End Blend Strengths.
100% Viscose

	Strength, Lbs.	Elongation, Percent	Tenacity, Gms./Denier
	0.73	18.0	2.192
	0.74	18.6	2.238
	0.74	19.2	2.238
	0.74	19.2	2.238
	0.74	19.2	2.238
	0.76	19.8	2.298
	0.76	18.6	2.298
	0.75	19.2	2.268
	0.73	19.2	2.208
	0.74	18.6	2.238
Mean	0.742	18.96	2.245
Coefficient of Variation, Percent			1.53

Table 17. Single End Blend Strengths.
50/50 Dacron/Viscose

	Dacron Break		Viscose Break		Viscose
	Strength, Lbs.	Elongation, Percent	Strength, Lbs.	Elongation, Percent	Tenacity Gms./Denier
	4.70	12.6	0.80	19.2	2.419
	4.80	12.0	0.75	18.6	2.268
	4.60	13.8	0.80	21.6	2.419
	4.50	12.0	0.80	19.2	2.419
	4.60	12.0	0.80	18.0	2.419
	4.65	12.0	0.80	19.2	2.419
	4.50	13.2	0.75	19.2	2.268
	4.65	12.0	0.75	18.6	2.268
	4.70	12.0	0.80	18.0	2.419
	4.65	11.4	0.80	19.2	2.419
Mean	4.635	12.30	0.785	19.08	2.374
Coefficient of Variation, Percent					3.07

Table 18. Single End Blend Strengths.
100% Acetate

	Strength, Lbs.	Elongation, Percent	Tenacity, Gms./Denier
	0.40	28.2	1.210
	0.41	28.2	1.240
	0.41	25.2	1.240
	0.41	28.2	1.240
	0.40	28.8	1.210
	0.41	28.8	1.240
	0.41	28.8	1.240
	0.40	27.6	1.210
	0.41	29.4	1.240
	0.42	28.2	1.270
Mean	0.408	28.14	1.234
Coefficient of Variation, Percent			1.54

Table 19. Single End Blend Strengths.
50/50 Dacron/Acetate

	Dacron Break		Acetate Break		Acetate
	Strength, Lbs.	Elongation, Percent	Strength, Lbs.	Elongation, Percent	Tenacity Gms./Denier
	4.30	11.4	0.44	28.8	1.331
	4.45	12.0	0.42	28.8	1.270
	4.30	12.0	0.43	29.4	1.300
	4.40	12.0	0.42	28.8	1.270
	4.35	11.4	0.42	28.8	1.270
	4.35	12.0	0.41	26.4	1.240
	4.20	12.6	0.41	26.4	1.240
	4.30	10.8	0.40	27.6	1.210
	4.30	12.0	0.40	28.8	1.210
	4.20	12.0	0.42	28.2	1.270
Mean	4.315	11.82	0.417	28.20	1.261
Coefficient of Variation, Percent					2.99

Table 20. Single End Blend Strengths
50/50 Viscose/Acetate

	Viscose Break		Acetate Break		Acetate
	Strength, Lbs.	Elongation, Percent	Strength, Lbs.	Elongation, Percent	Tenacity Gms./Denier
	1.06	19.2	0.42	30.0	1.270
	1.08	20.4	0.38	26.4	1.149
	1.11	19.8	0.42	29.4	1.270
	1.10	19.2	0.41	27.6	1.240
	1.10	19.2	0.40	28.2	1.210
	1.08	18.0	0.40	27.6	1.210
	1.08	18.6	0.41	28.8	1.240
	1.12	19.2	0.40	28.8	1.210
	1.11	19.2	0.42	27.0	1.270
	1.06	18.0	0.40	27.0	1.210
Mean	1.09	19.08	0.406	28.08	1.228
Coefficient of Variation, Percent					3.11

Table 21. Single End Blend Strengths.
100% Nylon

	Strength, Lbs.	Elongation, Percent	Tenacity, Gms./Denier
	2.60	26.4	5.896
	2.55	29.4	5.783
	2.60	28.8	5.896
	2.60	28.2	5.896
	2.60	27.6	5.896
	2.60	28.2	5.896
	2.60	30.0	5.896
	2.65	31.2	6.010
	2.65	32.4	6.010
	2.65	31.2	6.010
Mean	2.610	29.34	5.919
Coefficient of Variation, Percent			1.21

Table 22. Single End Blend Strengths.
50/50 Dacron/Nylon

	Dacron Break		Nylon Break		Nylon
	Strength, Lbs.	Elongation, Percent	Strength, Lbs.	Elongation, Percent	Tenacity Gms./Denier
	6.35	13.8	2.60	27.0	5.896
	6.25	12.6	2.55	30.0	5.783
	6.20	13.2	2.55	25.8	5.783
	6.05	12.0	2.55	28.8	5.783
	6.10	14.4	2.55	31.2	5.783
	5.85	12.0	2.60	27.6	5.896
	6.25	13.2	2.65	28.8	6.010
	5.80	12.0	2.55	29.6	5.783
	6.30	13.2	2.55	29.6	5.783
	6.10	12.0	2.65	30.6	6.010
Mean	6.125	12.84	2.58	28.82	5.851
Coefficient of Variation, Percent					1.63

Table 23. Single End Blend Strengths.
50/50 Viscose/Nylon

	Viscose Break		Nylon Break		Nylon
	Strength, Lbs.	Elongation, Percent	Strength, Lbs.	Elongation, Percent	Tenacity Gms./Denier
	3.20	20.4	2.60	29.4	5.896
	3.25	18.6	2.60	28.2	5.896
	3.25	19.2	2.60	30.0	5.896
	3.20	19.2	2.65	30.6	6.010
	3.25	18.6	2.60	25.2	5.896
	3.25	21.6	2.55	28.8	5.783
	3.25	19.2	2.65	28.8	6.010
	3.20	18.6	2.55	28.8	5.783
	3.25	19.2	2.55	29.4	5.783
	3.25	19.2	2.60	28.8	5.896
Mean	3.235	19.38	2.595	28.80	5.885
Coefficient of Variation, Percent					1.42

Table 24. Single End Blend Strengths.
50/50 Acetate/Nylon

	Break, Lbs.	Elongation, Percent
	2.95	27.0
	3.05	29.4
	3.00	28.8
	2.95	28.8
	2.95	28.2
	2.95	27.6
	3.00	28.8
	2.95	30.6
	3.00	20.0
	3.05	29.4
Mean	2.985	28.86

Table 25. Multiple End Break Strengths.
100% Dacron

	Break, Lbs.	Tenacity, Gms./Denier
	37.5	7.732
	38.0	7.835
	38.0	7.835
	38.5	7.938
	38.5	7.938
	38.0	7.835
	38.0	7.835
	38.5	7.938
	38.0	7.835
	38.5	7.938
Mean	38.15	7.866
Coefficient of Variation, Percent		0.88

Table 26. Multiple End Break Strengths.
100% Viscose

	Break, Lbs.	Tenacity, Gms./Denier
	12.2	2.460
	12.0	2.419
	12.2	2.460
	12.3	2.480
	12.2	2.460
	12.2	2.460
	12.0	2.419
	12.2	2.460
	11.9	2.400
	12.2	2.460
Mean	12.14	2.448
Coefficient of Variation, Percent		1.04

Table 27. Multiple End Break Strengths.
25/75 Dacron/Viscose

	Dacron Break, Lbs.	Viscose Break, Lbs.	Viscose Tenacity, Gms./Denier
	23.5	11.0	2.218
	23.5	11.5	2.318
	23.0	11.0	2.218
	23.5	11.0	2.318
	23.5	11.5	2.318
	23.5	11.0	2.218
	23.5	11.0	2.218
	23.5	10.5	2.117
	24.0	11.0	2.218
	23.5	10.5	2.117
Mean	23.50	11.00	2.218
Coefficient of Variation, Percent			3.02

Table 28. Multiple End Break Strengths.
50/50 Dacron/Viscose

	Dacron Break, Lbs.	Viscose Break, Lbs.	Viscose Tenacity, Gms./Denier
	32.5	8.0	2.419
	32.5	8.0	2.419
	33.0	8.0	2.419
	32.5	8.0	2.419
	32.5	8.0	2.419
	32.5	8.0	2.419
	32.5	8.0	2.419
	33.0	7.5	2.268
	32.5	7.5	2.268
	32.0	8.0	2.419
Mean	32.55	7.90	2.389
Coefficient of Variation, Percent			2.67

Table 29. Multiple End Break Strengths.
75/25 Dacron/Viscose

	Dacron Break, Lbs.	Viscose Break, Lbs.	Viscose Tenacity, Gms./Denier
	41.0	4.25	2.570
	41.0	4.25	2.570
	39.5	4.00	2.419
	41.5	4.25	2.570
	41.0	4.25	2.570
	41.5	4.00	2.419
	41.5	4.50	2.419
	41.0	4.25	2.570
	41.0	4.25	2.570
	41.0	4.00	2.419
Mean	41.00	4.16	2.510
Coefficient of Variation, Percent			3.11

Table 30. Multiple End Break Strengths.
100% Acetate

	Break, Lbs.	Tenacity, Gms./Denier
	6.3	1.270
	6.2	1.250
	6.3	1.270
	6.2	1.250
	6.3	1.270
	6.3	1.260
	6.4	1.290
	6.0	1.210
	6.3	1.260
	6.3	1.260
Mean	6.245	1.259
Coefficient of Variation, Percent		1.65

Table 31. Multiple End Break Strengths.
25/75 Dacron/Acetate

	Dacron Break, Lbs.	Acetate Break, Lbs.	Acetate Tenacity, Gms./Denier
	18.5	5.7	1.231
	18.6	5.6	1.210
	18.4	5.7	1.231
	19.2	5.8	1.253
	18.8	5.8	1.253
	19.0	5.8	1.253
	18.8	5.8	1.253
	18.9	5.6	1.210
	19.1	5.8	1.253
	19.0	5.6	1.210
Mean	18.83	5.72	1.236
Coefficient of Variation, Percent			1.60

Table 32. Multiple End Break Strengths.
50/50 Dacron/Acetate

	Dacron Break, Lbs.	Acetate Break, Lbs.	Acetate Tenacity, Gms./Denier
	29.0	4.25	1.285
	29.0	4.00	1.210
	29.0	4.25	1.285
	29.0	4.25	1.285
	29.5	4.25	1.285
	29.0	4.25	1.285
	29.0	4.00	1.210
	29.5	4.00	1.210
	29.0	4.25	1.285
	29.0	4.00	1.210
Mean	29.10	4.15	1.255
Coefficient of Variation, Percent			3.09

Table 33. Multiple End Break Strengths.
75/25 Dacron/Acetate

	Dacron Break, Lbs.	Acetate Break, Lbs.	Acetate Tenacity, Gms./Denier
	39.0	2.25	1.361
	39.5	2.25	1.361
	39.5	2.25	1.361
	39.5	1.75	1.058
	39.0	2.25	1.361
	39.0	2.00	1.210
	39.5	2.00	1.210
	39.5	2.00	1.210
	40.0	2.00	1.210
	40.0	2.25	1.361
Mean	39.45	2.10	1.270
Coefficient of Variation, Percent			8.33

Note: The magnitude of the CV for this test case is somewhat larger than the other test cases.

Table 34. Multiple End Break Strengths.
25/75 Viscose/Acetate

	Viscose Break, Lbs.	Acetate Break, Lbs.	Acetate Tenacity, Gms./Denier
	9.3	6.3	1.270
	9.3	6.4	1.290
	9.5	6.3	1.270
	9.1	6.3	1.270
	9.4	6.4	1.290
	9.3	6.2	1.250
	9.2	6.2	1.250
	9.2	6.4	1.290
	9.0	6.3	1.270
	9.3	6.4	1.290
Mean	9.26	6.32	1.274
Coefficient of Variation, Percent			1.24

Table 35. Multiple End Break Strengths.
50/50 Viscose/Acetate

	Viscose Break, Lbs.	Acetate Break, Lbs.	Acetate Tenacity, Gms./Denier
	11.6	4.3	1.300
	11.1	4.2	1.270
	11.5	4.2	1.270
	11.5	4.2	1.270
	11.7	4.2	1.270
	11.5	4.3	1.300
	11.2	4.2	1.270
	11.4	4.2	1.270
	11.7	4.2	1.270
	11.5	4.3	1.300
Mean	11.47	4.23	1.279
Coefficient of Variation, Percent			1.13

Table 36. Multiple End Break Strengths.
75/25 Viscose/Acetate

	Viscose Break, Lbs.	Acetate Break, Lbs.	Acetate Tenacity, Gms./Denier
	13.7	2.1	1.270
	13.6	2.1	1.270
	13.3	2.1	1.270
	13.7	2.1	1.270
	13.2	2.1	1.270
	13.0	2.1	1.270
	13.7	2.1	1.270
	13.2	2.1	1.270
	13.6	2.1	1.270
	13.2	2.1	1.270
Mean	13.42	2.1	1.270
Coefficient of Variation, Percent			0.0

Table 37. Multiple End Break Strengths.
100% Nylon

	Break, Lbs.	Tenacity, Gms./Denier
	27.5	5.670
	27.5	5.670
	28.3	5.825
	28.0	5.773
	27.8	5.722
	27.8	5.722
	27.8	5.722
	27.8	5.722
	28.0	5.773
	28.0	5.773
Mean	27.82	5.737
Coefficient of Variation, Percent		0.85

Table 38. Multiple End Break Strengths.
25/75 Dacron/Nylon

	Dacron Break, Lbs.	Nylon Break, Lbs.	Nylon Tenacity, Gms./Denier
	23.0	17.75	5.751
	23.0	18.00	5.832
	22.5	18.00	5.832
	22.5	18.00	5.832
	23.5	18.00	5.832
	22.5	18.00	5.832
	22.5	17.50	5.670
	22.5	17.75	5.757
	23.5	18.00	5.832
	23.0	18.00	5.832
Mean	22.86	17.90	5.800
Coefficient of Variation, Percent			0.98

Table 39. Multiple End Break Strengths.
50/50 Dacron/Nylon

	Dacron Break, Lbs.	Nylon Break, Lbs.	Nylon Tenacity, Gms./Denier
	30.0	13.0	5.897
	30.5	13.0	5.897
	30.5	13.0	5.897
	30.5	13.0	5.897
	30.0	13.0	5.897
	30.5	13.0	5.897
	30.5	13.0	5.897
	30.0	13.0	5.897
	30.0	13.0	5.897
	31.0	13.0	5.897
Mean	30.35	13.0	5.897
Coefficient of Variation, Percent			0.0

Table 40. Multiple End Break Strengths
75/25 Dacron/Nylon

	Dacron Break, Lbs.	Nylon Break, Lbs.	Nylon Tenacity, Gms./Denier
	28.0	5.25	5.953
	28.5	5.50	6.237
	28.5	5.25	5.953
	28.5	5.25	5.953
	28.5	5.25	5.953
	28.0	5.50	6.237
	28.5	5.50	6.237
	28.5	5.25	5.953
	27.5	5.25	5.953
	27.5	5.50	6.237
Mean	28.20	5.35	6.067
Coefficient of Variation, Percent			2.42

Table 41. Multiple End Break Strengths.
25/75 Viscose/Nylon

	Viscose Break, Lbs.	Nylon Break, Lbs.	Nylon Tenacity, Gms./Denier
	31.5	27.75	5.722
	31.5	27.75	5.722
	30.0	27.75	5.722
	31.0	28.00	5.773
	31.5	28.00	5.773
	31.0	27.00	5.567
	31.0	27.50	5.670
	31.0	27.50	5.670
	31.5	27.50	5.670
	31.5	27.75	5.722
Mean	31.15	27.65	5.701
Coefficient of Variation, Percent			1.06

Table 42. Multiple End Break Strengths.
50/50 Viscose/Nylon

	Viscose Break, Lbs.	Nylon Break, Lbs.	Nylon Tenacity, Gms./Denier
	25.5	17.75	5.751
	25.5	18.00	5.832
	25.0	18.00	5.832
	25.0	17.75	5.751
	25.5	18.00	5.832
	25.5	18.00	5.832
	25.5	17.75	5.751
	25.0	18.00	5.832
	25.0	17.75	5.751
	24.5	17.75	5.751
Mean	25.20	17.88	5.792
Coefficient of Variation, Percent			0.74

Table 43. Multiple End Break Strengths.
75/25 Viscose/Nylon

	Viscose Break, Lbs.	Nylon Break, Lbs.	Nylon Tenacity, Gms./Denier
	19.5	10.25	5.812
	21.5	10.00	5.670
	22.0	10.00	5.670
	21.0	10.00	5.670
	21.5	10.25	5.812
	20.5	10.50	5.954
	20.5	10.25	5.812
	21.0	10.25	5.812
	20.0	10.25	5.812
	20.5	10.25	5.812
Mean	20.80	10.20	5.784
Coefficient of Variation, Percent			1.55

Table 44. Multiple End Break Strengths
25/75 Acetate/Nylon

Strength, Lbs.
29.0
29.0
29.5
29.5
30.0
29.5
30.0
29.5
30.0
29.5
29.55

Table 45. Multiple End Break Strengths
50/50 Acetate/Nylon

Strength, Lbs.
22.0
21.0
21.0
22.0
22.0
21.5
21.0
22.0
22.0
21.5
21.60

Table 46. Multiple End Break Strengths.
75/25 Acetate/Nylon

Strength, Lbs.
16.5
16.4
16.7
16.2
16.3
16.6
16.5
16.5
16.4
16.4
16.45

APPENDIX C

SELECTIVE SUBJECT BIBLIOGRAPHY

SELECTIVE SUBJECT BIBLIOGRAPHY

after Backer and Hearle *et al*.,

with additions on blending by the author.

LC refers to Literature Cited. LNC refers to literature Not Cited. With the reference number corresponding to LC or LNC, the full citation may be obtained from the respective section of the Bibliography.

Author	Date of Publication	Bibliographic Citation
	Packing of Fibers in Yarns	
Schwarz	1933	LC 84
Schwarz	1951	LNC 60
	Specific Volume of Yarns	
Gulati and Turner	1930	LNC 24
Schwarz	1933	LC 84
Gee	1939	LNC 13
Gregory	1950	LNC 15-17
Barella	1950	LNC 3
Morton	1959	in LNC 47
Hamilton	1959	LNC 28
Van Issum and Chamberlain	1959	LNC 69
Hearle and Merchant	1963	LNC 34
	Migration of Fibers and Filaments in Yarns	
Peirce	1947	LNC 50
Morton and Yen	1952	LC 17
Morton	1956	LC 18
Riding	1959	LC 16
Kilby	1959	LC 32
Hearle, El-Behery and Thakur	1959	LC 28
Hearle and Thakur	1961	LC 29

(Continued)

Author	Date of Publication	Bibliographic Citation
Migration of Fibers and Filaments in Yarns (Concluded)		
Zurek	1961	LC 30
Hearle and Merchant	1962	LNC 33
Gupta	1963	LNC 23
Riding	1964	LC 31
Yarn Twist Contraction: Theoretical		
Gregory	1950	LNC 15
Treloar	1956	LC 14
Hearle and Morton	1957	LNC 35
Kilby	1959	LC 32
Zurek	1961	LC 30
Yarn Twist Contraction: Experimental		
Landstreet, Ewald and Simpson	1957	LNC 43
Tattersall	1958	LC 15
Riding	1959	LC 16
Hearle, El-Behery and Thakur	1960	LNC 31
Staple Fiber Yarns: Theory of Mechanics of		
Gegauff	1907	LC 8
Peirce	1926	LC 68
Peirce	1947	LNC 50
Platt	1950	LNC 51
Gregory	1950	LNC 15-19
Morton	1956	LC 18
Shorter	1957	LNC 61
Extension and Breakage of Spun Yarns		
Platt	1950	LNC 51
Platt, Klein and Hamburger	1952	LC 13
Platt, Klein and Hamburger	1954	LNC 56
Landstreet, Ewald and Simpson	1957	LNC 43

Theory of Tensile Properties
of Twisted Continuous Filament Yarns

Author	Date of Publication	Bibliographic Citation	Nature of Work
Gegauff	1907	LC 8	Theory of spun yarns, but includes basic equation of simplest treatment of filament yarns.
Platt	1950	LC 10 LNC 52	Tensile forces only: includes effects of lateral contraction, large extensions and deviations from Hooke's Law.
Hearle	1958	LC 9	Tensile and transverse forces: small strains, Hooke's Law, no lateral contraction.
Hearle, El-Behery and Thakur	1961	LNC 32	(i) Tensile and transverse strains, Hooke's Law with lateral contraction. (ii) Tensile forces only: large strains, lateral contraction, deviations from Hooke's Law.
Treloar and Hearle	1962	LNC 36	Corrects error in previous two papers.
Treloar and Riding	1963	LC 72	Energy method - includes effects of transverse forces, constant volume deformation, large strains, deviations from Hooke's Law.
Stansfield	1958	LC 24	
Symes	1959	LNC 64	Cord properties, with approximations.
Zurek	1961	LC 30	
Treloar	1956	LC 14	

Experimental Studies of Tensile Properties of Continuous Filament Yarns

Author	Date of Publication	Bibliographic Citation	Nature of Work
		(a) Modulus	
Hamburger	1948	LNC 25	Acetate and nylon - sonic modulus.
Maginnis	1950	LNC 46	Viscose rayon - sonic and static modulus.
		(b) Tenacity and Breaking Extension	
Platt	1950	LC 10	Viscose rayon and acetate.
Taylor *et al*.	1952	LC 71	Viscose rayon, nylon, Dacron.
Alexander and Sturley	1952	LNC 1	Nylon.
Shrinagbushan	1956	LNC 62	Viscose rayon.
Grover and Hamby	1956	LNC 21	Viscose rayon, acetate, nylon, Dacron, Orlon.
Hearle and Thakur	1961	LC 29	Viscose rayon, acetate, nylon, Terylene.
		(c) Full Stress-Strain Curves	
Hearle, El-Behery and Thakur	1960 1959	LC 28 LNC 31	Viscose rayon, acetate, nylon, Terylene.
Treloar and Riding	1963	LC 72	Viscose rayon.

Fiber Blending

Author	Date of Publication	Bibliographic Citation	Nature of Work
The Textile Inst.	1952	LNC 65	Conference on blends.
Sayre	1955	LC 54	Orlon, nylon, viscose rayon,acetate, Dacron.
Kemp and Owen	1955	LC 38	Cotton/nylon.
Cirlic and Kokojan	1956	LNC 7	Wool/synthetics
Noshi, Ishida and Shimada	1960	LC 48	Rayon, nylon, Dacron.
Matukonis	1961	LC 67	Nylon, viscose, acetate.
Koritskii	1961	LC 39	Cotton/nylon.
Kogan	1962	LNC 41	Cotton/nylon.
Backer and Machida	1963	LC 40 LC 41	Cotton/nylon.

Translation of Fiber Properties Into Blended Yarn Strength

Author	Date of Publication	Bibliographic Citation
Hamburger	1949	LC 55
Whytlaw	1952	LC 1
Nuding	1952	LC 2
Dennison and Leach	1952	LC 65
Sattler	1954	LC 49
Coplan	1959	LC 50
Noshi, Ishida and Shimada	1960	LC 48
Louis, Fiori and Sands	1961	LC 63
		LC 64
Zurek	1960	LNC 73
Koritskii	1961	LC 39
	1961	LC 58
Birenbaum	1962	LNC 4
Owen	1962	LC 59
Backer	1963	LC 40

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